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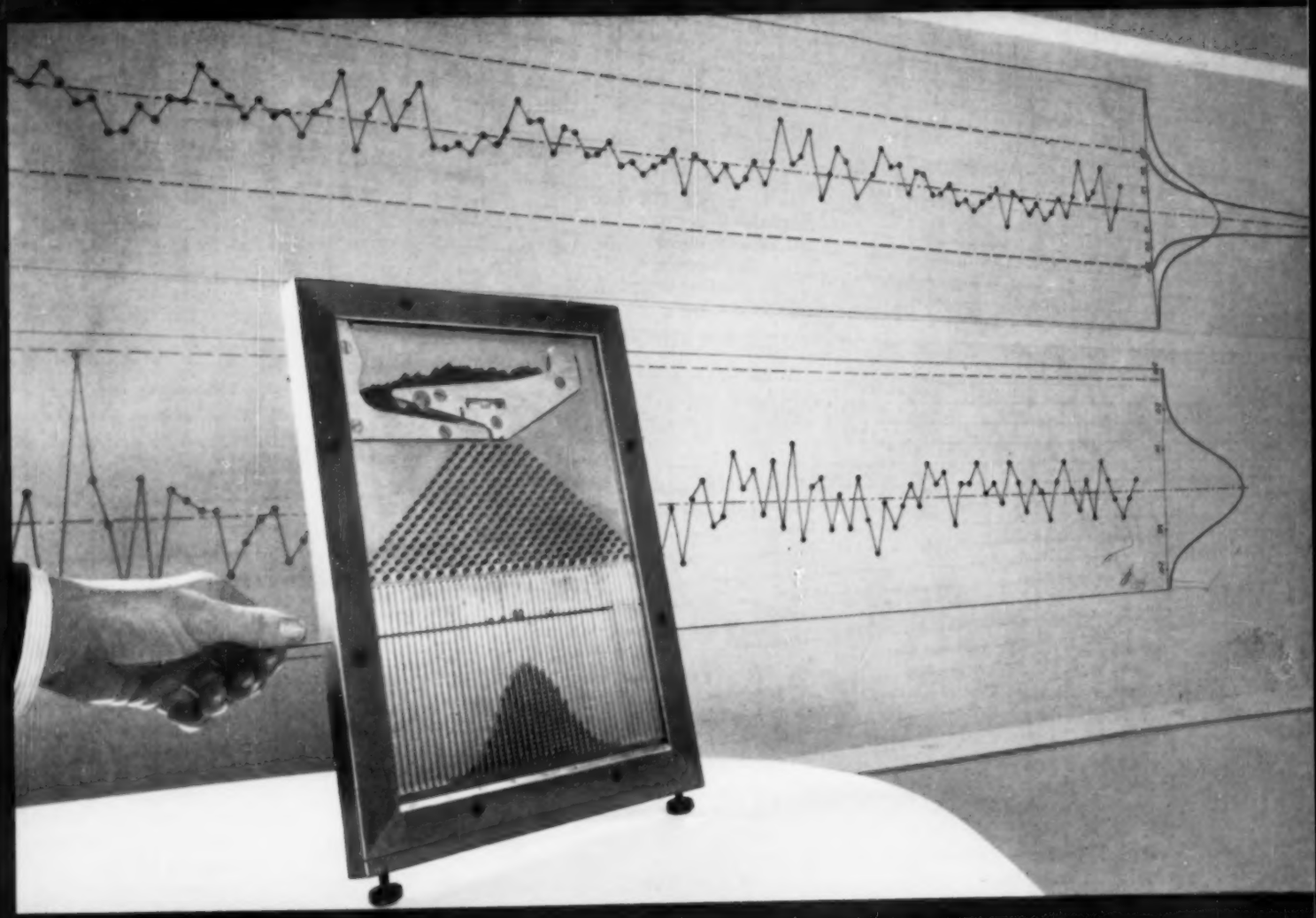

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IQC NEWS SUPPLEMENT

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A Quincunx Demonstrator

R. E. WAGENHALS

The Timken Roller Bearing Company

The quincunx on the cover is an effective tool to show the principles of quality control average and range charts. It's small construction lends itself to effective 15 minute demonstrations in foreman's offices and to small groups of people. It is 10" × 14½" × 1" in size, employing 500 one-eighth inch diameter balls. The pins which are pressed into the solid aluminum back are covered with plastic tubes to prevent the balls from bouncing. The wire stops any desired number of balls, dropped by a lever in the back, and makes it possible to get individual values from which average and range charts may be made. Small horizontal markings on the vertical slots indicate the height of ten balls so that the number of balls for each individual value can be easily determined.

The demonstration is made by first covering the area below the pull wire with cardboard. $\overline{X}$ and R control charts, like those in the background, are plotted by dropping the balls in groups of five and recording the values. At the same time the trainees are asked to keep an accurate tally of the frequency for each individual reading. Before the demonstration is finished a simple explanation is made of the theoretical percentages of balls that should fall in zones $\pm 1\sigma$, $\pm 2\sigma$, $\pm 3\sigma$. The cardboard is removed and the distribution of balls in the quincunx is analyzed by the zones. This distribution of balls has always been very close to the theoretical number in each zone.

The charts in the photograph were made by operating the quincunx using samples of five. The frequency distributions at the end of the charts are for averages, individuals, and ranges. The fact that the demonstrator can very accurately predict the number of balls falling within the zones in a very impressive demonstration to foremen. This device was built by Timken Roller Bearing Company and used as a part of the quality control training to hundreds of foremen and line inspectors.

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Industrial Quality Control

Vol. VI **MARCH, 1950** **No. 5**

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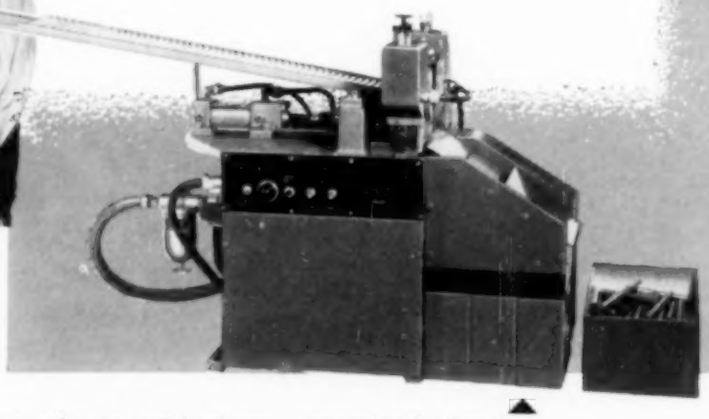
This single-motor, compact machine automatically gages and sorts antifriction bearing rolls. It rejects rolls above or below manufacturing tolerance and separates accepted rolls into 5 sized categories, in increments of .00002".



This machine gages and sorts straight sleeves—measuring for length as well as diameter at both ends. The sleeves are segregated into four categories. **1.** *Oversize and undersize in length regardless of diameter.* **2.** *Small in diameter at either or both ends.* **3.** *Large in diameter at either or both ends.* **4.** *Good sleeves within tolerance.*

The machine has a production rate of approximately 3000 per hour. The capacity is adjustable for different lengths and diameters. It is loaded manually with automatic disposal.

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Practical Applications of New Theory
A Review

PART IV. GATHERING INFORMATION

FREDERICK MOSTELLER, *Harvard University, and* JOHN W. TUKEY, *Princeton University*

THIS IS the last of four parts. It covers process control, planning experimentation, searching for a maximum, special experimental designs, and where to get journals and tables.

PROCESS CONTROL

Although quality control people are by now familiar with Dodge's "Sampling inspection plan for continuous production" [Annal of Math. Stat. 14 (1943) 264-279], a review of mathematical advances must necessarily include this concept. The purpose of Dodge's plan is to attain a limiting percent defective (AOQL) when inspecting items coming successively from a production line.

The principal idea is:

a) Inspect 100% until i units in succession are clear of defects.
b) Then inspect only the fraction f of units until one is found defective.
c) Then revert to 100% inspection until i units in succession are clear of defects, etc.
d) Correct or replace with good units all defective units found.

Those interestd in process control may also wish to examine the paper of A. Wald and J. Wolfowitz, "Sampling inspection plans for continuous production which insure a prescribed limit on outgoing quality" [Annals of Math. Stat. 16 (1945) 30-50]. The methods of this paper are designed for the same purpose as that of Dodge. They guarantee that certain rather pathological situations cannot upset the sampling plan, but they are more complicated to use. The main feature is the continuous computation of a ratio which depends on the number of defectives and non-defectives observed. Decisions to change from 100% inspection to sampling or vice versa depend on the values assumed by the ratio.

PLANNING EXPERIMENTATION

The problem of the correct scale of experiment to detect an assumed difference with a given probability is common to all fields. Marilyn Harris, D. G. Horvits, and A. M. Mood ["On the determination of sample sizes in designing experiments", J. Amer. Stat. Assn. 43 (1948) 391-402] have reconsidered this problem and found that the old procedures were inadequate. New tables are needed, and have been provided for the most common cases which arise with a single mean or the difference of two means. The essential change from past considerations is an allowance for the fallibility of our estimate of the error variability.

Some of these considerations involve the non-central t-distribution, many of whose applications have been reviewed by N. L. Johnson and B. L. Welch ["Applications of the non-central t-distribution", Biometrika 31 (1939-40) 623-389], who give complete tables and a simple and effective approximation.

THE SEARCH FOR A MAXIMUM

One of the difficult experimental problems in metallurgy is to find the particular combination of a number of metals which will maximize some desirable characteristic of the resulting alloy. This problem appears in many other guises. When there are a number of variables involved such as temperature, length of time, and various possible amounts of each ingredient, the problem of finding the optimum combination requires very many observations. Usually in such experiments the cost of a single observation is high. Therefore any help the statistician or mathematician can give is likely to be very welcome, even if the computations involved are usually tediously long.

The pathbreaking work on this problem was done by Hotelling ["The experimental determination of the maximum of a function", Annals of Math. Stat. 12 (1941) 20-45]. Hotelling's method was mainly that of fitting parabolas or paraboloids to the data. Once a parabola or paraboloid is fitted we can find its maximum and use this as a center for conducting new experiments in the neighborhood of this approximate maximum.

More recently Friedman and Savage ["Planning experiments seeking maxima", Techniques of Statistical Analysis, SRG-Columbia, McGraw-Hill, (1947) 365-372] have considered the problem of designing such experiments.

They point out that a factorial design (spacing the observations over a grid) is not a reasonable way to proceed in such an experiment because it is so expensive. The factorial design increases the number of observations very rapidly with the number of dimensions. If we have 7 variables and decide to choose 3 values of each variable there will be $3^7 = 2187$ points or observations to be taken. Clearly three values on each variable are not many. The intuitive view is that there must be a better way of distributing the points, because the factorial design leads to examination of parts of the function which do not give information commensurable with the cost. These authors suggest a sequential design. The essential process is to put the variables in some order. Then change the value of the first variable only until the dependent variable is maximized. Hold the first variable fixed at that maximum and change only the second variable until a new maximum is obtained, etc. The method is a rather commonsense one. Curve fitting or other elaborations may be combined with the method.

Rumors of a compromise method, developed in England by G. E. P. Box, have reached us, but nothing seems to have been published about it.

SPECIAL DESIGNS

Although none of the following designs can be used very often, there may be special occasions when they will prove useful.

For example, Dorfman writes on the "Detection of defective members of large populations" [Annals of Math. Stat. 14 (1943) 436-440]. His particular problem is the detection of syphillis by means of a "Wassermann-type" blood test. This test has the property that it can detect the presence or absence of "syphilitic antigen" in a pool of blood tests as well as in an individual test.

Now instead of testing each individual for presence or absence of the characteristic, he suggests pooling the blood of a number of individuals. Absence of the characteristic on the pooled lists implies absence of the characteristic for all the individuals in the pool, while presence in the pool implies that we must retest the individuals in the pool to sort out the "defective individuals".

The optimum size for pools depends on the proportion of defective individuals in the population. For example if the percent defective is 1%, then the optimum pool size is 11 with a saving of 80% in inspection over inspecting each individual. When the percentage defective increases, the amount of testing goes up and the reduction of testing is decreased. With 30% defective the optimum pool size of 3 saves only 1%. Dorfman supplies a table and graph showing optimum sizes of pool and relative savings.

Some such scheme might be useful in pharmaceutical or chemical testing for impurities or contamination when available tests are sufficiently sensitive and there are many such tests to be performed.

In connection with quality control charts for destructive tests, Paul H. Jacobsen ["The relative power of three statistics for small sample destructive tests", J. Amer. Stat. Assn. 42 (1947) 575-584] has suggested a special device. Suppose that we are testing the blowing of 5 fuses by placing them in a panel where the fuses will blow in succession from small amperage to large. If we stopped the test after the first three had blown, we would have the three smallest observations from a sample of 5. The remaining two items would be nearly as good as new. In life tests a similar argument applies except that we save time rather than items.

Now it turns out that if we use the mean of the three smallest items for a control chart we get an observation which is as good as the mean of 4 items in a sample of 4. In other words, merely by placing two extra fuses in the panel the tester obtains information equivalent to 4 units at the cost of destroying only 3 units.

It must be made quite clear that the result is a biased estimate of the mean. However, for controlling the **level** of quality, this is not of great importance. We can set our control limits around this biased estimate just as well as around the mean. We can get a range chart if we wish from the three observations we have. For the purpose of quality control therefore, we can continue to check both level and variability. In principle this method could be extended to larger samples, although this has not been done so far.

Anyone interested in life tests in service will want to read "Tumbler mortality" by G. W. Brown and M. M. Flood [J. Amer. Stat. Assn. 42 (1947) 562-574]. The authors have the problem of measuring the mean length of life of glass tumblers of two types—annealed and toughened. Experiments were carried out in service in a test cafeteria. An important complication in such experiments is that the experiment is necessarily of finite length. This leads to truncated samples, i.e., we have measurements on the items which have "died", but there are a number of items which have not "died". If we include only measurements from lots that have all died the experiment will be unendurably long or else we will have practically no data on which to base our life estimates.

The authors solve this problem by fitting their data to the incomplete gamma function by the special device of minimizing chi-square. They also derive from technological considerations some possible tumbler mortality curves. In particular, they find that the Makeham-Gompertz mortality curve, which could be used to approximate the incomplete gamma function, would be one reasonable mortality curve to use.

One model for tumbler breakage is that the tumbler breaks when it is bumped for the nth time and that the number of bumps is proportional to the time in service. With this model one gets exactly the incomplete gamma function—but the data suggest that the number of bumps would need to be about 1.55 or 1.60 for the two types of tumblers. Thus a better explanation for the success of the incomplete gamma function is needed.

JOURNALS AND SOCIETIES

Some of the developments we have discussed were published in obscure journals, but a very large number were in four journals. We shall describe them briefly, and indicate how they can be obtained. Where a journal normally accompanies membership in a society, an individual will usually find it best to join the society.

Biometrics presents statistical and mathematical techniques for the user. Examples are likely to be biological, but the techniques have wide application. An interesting query column answers many elementary and advanced problems. Quarterly. Accompanies membership in the Biometric Society (and in the Biometric Section of the American Statistical Association). Subscriptions and back numbers from Professor Gertrude M. Cox, Institute of Statistics, North Carolina State College, Raleigh, N. C. Application blanks for the Biometric Society from Dr. Chester I. Bliss, Box 1106, New Haven, Conn. (Although mainly interested in biological applications, the Biometric Society welcomes others interested in applying the same techniques to other fields, and a few percent of its present membership give "quality control or industrial statistics" as their main interest. The writers will be glad to serve as the necessary sponsors for 99.44% of the readers of **Industrial Quality Control.**)

Biometrika, an English journal founded by Karl Pearson, has been the best-known journal of statistical method for more than forty years. More tables of statistical interest are published here than in any other journal. Twice a year. Special rate to members of the Institute of Mathematical Statistics. Subscriptions and back numbers from the Biometrika Office, University College, London, W.C.1, England.

The Annals of Mathematical Statistics emphasizes heavily mathematical and theoretical statistics, with occasional excursions into methods and tables on the one hand and probability theory on the other. Accompanies membership in the Institute of Mathematical

Statistics. Quarterly. Subscriptions, back numbers, and membership applications from Professor Carl Fischer, Business Administration Building, University of Michigan, Ann Arbor, Michigan.

The Journal of the American Statistical Association covers a wide field, with statistical methods and applications to economics and business stressed. Quarterly. Accompanies membership in the American Statistical Association. Subscriptions, back numbers, and membership applications from the American Statistical Association, 1603 K Street, N.W., Washington 6, D. C.

TABLES

All but one of the tables in **Biometrika** referred to in Part I, and others as well, are available separately from the Biometrika Office, University College, London, W.C.1, England. Some are available from the Cambridge University Press, 51 Madison Ave., New York 10, New York.

Hald's tables are only available with his book "Statistike Metoder" printed by Fr. Bagtes Kgl. Hof-Bogtrykkeri, Copenhagen, Denmark. An English edition of both book and tables will be published (tentative date 1950) by John Wiley and Sons in the Wiley Mathematical Statistics Series edited by Walter A. Shewhart. It is understood that the book will carry some material not contained in the Danish edition which will be designed particularly for the American quality control audience.

CLOSING COMMENT

This review is incomplete, partly because we did not know about all the results, and partly because we left certain topics out as too large, too well reviewed, or too small. Perhaps someone else will do the job better in a few years time.

Diagnosis With Diagrams—Part II*

LEONARD A. SEDER

Quality Control Engineer, Gillette Safety Razor Company

CASE STUDY—GRAPHIC ANALYSIS of VARIANCE

While all of the material cited has certainly involved analysis of variance in the definitive sense, it has not resembled "analysis of variance" in the formal statistical sense. The latter term envisages the computation of certain standard statistical measures of variation by means of which an elaborate array of data may be reduced to a single number so as to permit an objective evaluation. Like the Reader's Digest version of a Tolstoy novel, this technique has the tremendous advantage of conveying the substance of the material in such a small package that its significance is readily grasped.

This benefit of ultra-condensation, however, is gained at the expense of giving the reader that important "feeling for" the novel which can be gotten only from the original. Applied to process diagnosis, the distilling of the data into a single compressed tablet sacrifices the opportunity to make "subdiagnoses" by scrutiny of some of the facets of the data. Moreover, those who must act on the diagnosis but are unfamiliar with the distillation process, i.e. the shop foreman, inspectors, operators, customers, suppliers and others have considerable difficulty swallowing the pill.

This is not to deny to formal analysis of variance its rightful place in the sun nor to deduct one whit from its importance in many situations. Rather it is to point out that, even in a case where formal analysis of variance would seem to serve the needs of the situation, much may be gained by undertaking supplementary graphical analysis or even by substituting it for the more rigorous treatment. Not the least of the unmentioned advantages is the elimination of the need for special computational training by those who actually prepare the information.

The following case will illustrate the point. It concerns the acceptance testing before purchase of a machine guaranteed by the maker to perform a certain operation within specified tolerances. The lack of mutual authority in such a situation imposes on the customer's representative both a burden and responsibility to employ a completely understandable method of communication of test results. The use of graphic techniques, it will be shown, accomplished a dual objective: it not only spared the customer the anguish of a tardy discovery of the vendor's shortcomings, but it clearly illuminated the path to be followed by the vendor to arrive at the desired culmination of the contract.

The machine was one designed to broach to size the copper part already discussed in the last example. Because the part involved is made of copper, some preliminary experimental work was undertaken by the maker to establish the basis for broach blade design. Following this, the machine was built. It consists of a duplicate pair of broaches, acting vertically, and a circular indexing feed-table. The table carries four pairs of work-stations which rotate from the loading position at the front to the broaching position at the rear. By means of cam-operated clamps, the front stations may be loaded while the rear ones are being broached. Figure 14 shows a schematic view of the operation.

When the machine was ready to operate, the customer's quality control technician was sent to the vendor's plant. He made a test run of 40 pieces—five successive pieces from each of the eight work stations. Each piece was measured at six positions, thus yielding 240 readings. A simple histogram (See lower part of Figure 15) of these readings immediately indicated that the machine was far from capable of meeting the specified tolerances. However, graphical techniques forced the data to reveal more than merely this discouraging news.

*Part I of this paper was published in the January 1950 issue of IQC.

A schematic layout of the data is shown in Table I. The statistician would recognize this as a multiple randomized block design and could readily break down the total variation into these sources:

(1) Between Broaches

(2) Among Stations within Broaches

(3) Among Positions within Broach—Stations

(4) Among Readings at a Broach—Station—Position

These four absorb all the degrees of freedom and there is no residual term. However, the fourth term may be regarded in this case as the basic machine capability, or random variability, and the other terms—which result from definite faults in the set-up of the tooling—would be tested against it for significance. It turned out that all three terms were significant,* which was fairly clear merely from an inspection of the raw data.

Since all three sources of variation were significant, the next step was to learn the relative significance of the individual sources, not in terms of probability but in terms of thousandths of an inch. It was necessary to know which one should be tackled first and how much of a change must be achieved.

Accordingly, two graphic aids were prepared to assist in this objective. The first was a Pictogram to show the total variability and the relative magnitude of each of the contributing sources. This involved simply the computation of the proper averages for each of the terms and the placing of these averages together as shown in Figure 15. The exact method employed and the practical significance of each source was as follows:

(1) **Broaches.** The average of the 120 readings from each of the two broaches. This measures the extent to which the two broaches are actually alike or the precision with which they have been located in their holders.

(2) **Stations.** The averages of the 30 readings for each of the four stations associated with each broach were first computed. For each broach, the highest and lowest **station average** are shown on graph.

*Actually, no analysis of variance was needed at the time. It was done later in order to be able to substantiate the above statement in this paper.

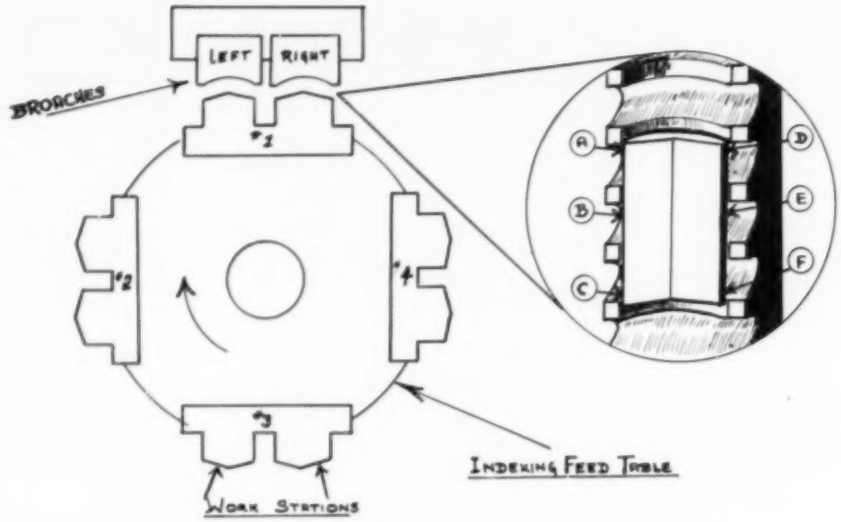

Figure 14—**Schematic View of Broaching Operation**

This is a measure of the extent to which the individual work-nests are alike in their dimensions, specially the dimensions which affect thickness of the piece.

(3) **Positions.** The averages of the five readings from each position are first computed for each of the eight stations. The highest and lowest **position average** for the particular stations chosen above were then plotted on the graph. This is a measure of the success with which each station has been aligned with its broach.

(4) **Machine Accuracy.** This is estimated by first computing the average range of the five readings at each position for the entire set of data and converting to standard deviation. The plotted values are plus

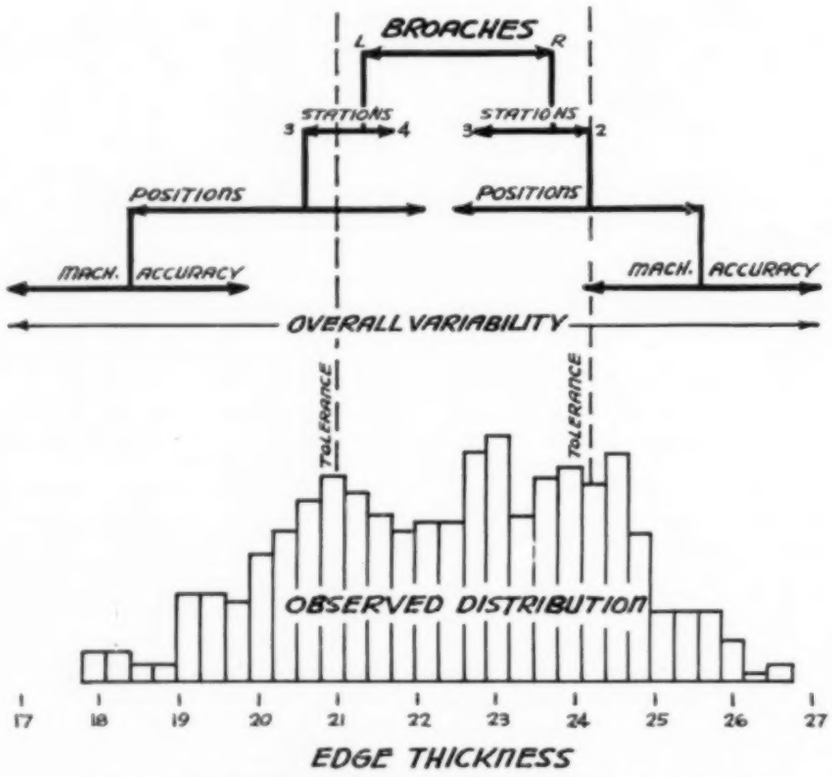

Figure 15—**Pictogram of First Test on Broaching Machine**

TABLE I—LAYOUT OF DATA

A.—LAYOUT FOR EACH STATION

	Position						
	A	B	C	D	E	F	
Left Broach	x	x	x	x	x	x	
	x	x	x	x	x	x	
	x	x	x	x	x	x	
	x	x	x	x	x	x	
	x	x	x	x	x	x	
	$\overline{X}_A$	$\overline{X}_B$	$\overline{X}_C$	$\overline{X}_D$	$\overline{X}_E$	$\overline{X}_F$	$\overline{X}_{S1L}$

B.—LAYOUT FOR COMPLETE TEST

	Station #1	Station #2	Station #3	Station #4	
Left Broach	$\overline{X}_{S1L}$	$\overline{X}_{S2L}$	$\overline{X}_{S3L}$	$\overline{X}_{S4L}$	$\overline{X}_L$
Right Broach	$\overline{X}_{S1R}$	$\overline{X}_{S2R}$	$\overline{X}_{S3R}$	$\overline{X}_{S4R}$	$\overline{X}_R$

x = individual reading

$\overline{X}_A$, $\overline{X}_B$ etc. = Average of 5 readings at a given position of a given station

$\overline{X}_{S1L}$ etc. = Average of 30 readings for Station #1. Left Broach

$\overline{X}_{S3R}$ etc. = Average of 30 readings for Station #3. Right Broach

$\overline{X}_L$, $\overline{X}_R$ = Average of 120 readings for Left and Right Broach, respectively

$\overline{X}$ = Grand Average of 240 Readings

and minus three standard deviations. This measures the chance variation in individual readings to be expected under long run conditions.

The philosophy underlying this treatment of the data follows. Since the Broach, Station and Position sources of variation are due to definite assignable causes and not to chance variation, we should not expect them to yield a normal distribution. This is especially true because of the small, finite number of broaches and stations. (i.e. the station averages, for example, are taken as indicating the magniture of station differences now existing in the machine, not as being samples from an infinite number of possible station maladjustments.) The Machine Accuracy source, on the other hand, does appear to be a chance phenomenon. Thus, the resulting overall variability should be a composite distribution made up of 48 small individual distributions. To predict the total process spread, therefore, it is necessary merely to locate the averages of the highest and lowest of these 48 distributions and add plus and minus three standard deviations of the Machine Accuracy variability. Location of the two extreme averages by showing the magniture of the three sources of variation responsible for their creation completes the picture.

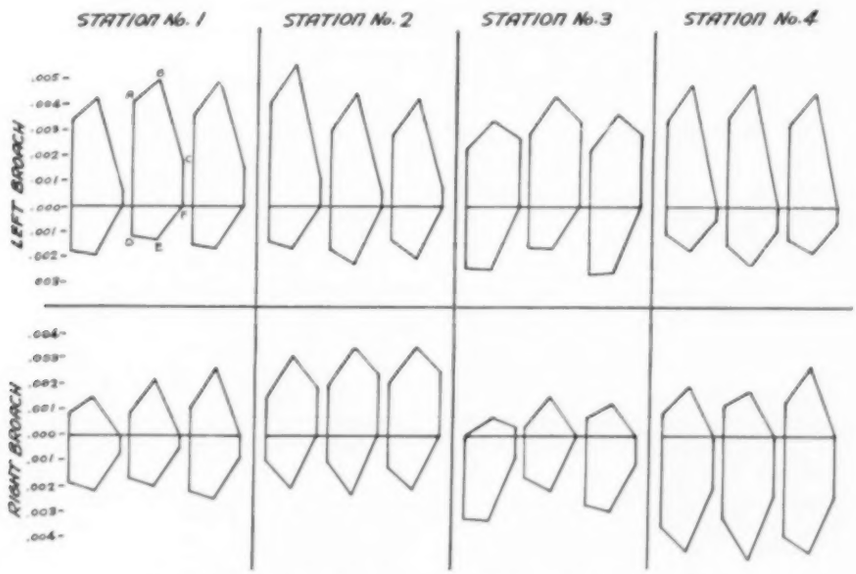

Figure 16—**P-D Diagrams for Eight Work-Stations**

Comparison of the predicted total variability of the Pictogram with the histogram of observed readings shows the close agreement attained.

It was obvious from observation of this diagram that Broaches and Positions were the two largest sources and should demand first attention. The corrective measure to reduce Broach difference was simply a refitting of the broach and broach holders; the Position effect was more complex, however, and required further analysis. This led to the preparation of the second graphic aid, shown in Figure 16.

Here the familiar P-D Diagrams are employed to show the exact direction in which each of the stations should be adjusted. When such diagrams were prepared for each of the 40 pieces (only 24 are shown here because of space limitations) and each was put in its place in the experimental layout, the significance of results could readily be judged without the need for a statistical analysis. Obvious stratification was seen to exist and the following diagnosis could be made:

(1) All pieces from stations associated with the left broach show an offside effect; the ABC side is thicker than the DEF side. Since this is common to all these stations, it probably results from an off-center condition on the broaching blade itself.

(2) The stations associated with the right broach do not all show the same offside pattern, hence each station must be individually adjusted. Stations #3 and #4, for example, require "upward" and station #2 "downward" adjustments (directions are with respect to the patterns of Figure 16; actual directions are leftward and rightward.)

(3) All diagrams show greater thickness at the centers than the corners, indicating less removal of copper by the broach in the middle of its stroke than at the beginning or end. This could be explained by the fact that the center section of the work-stations had been relieved, thus permitting elastic deformation of the copper under broaching load. New work-seats with unrelieved center sections were therefore indicated.

(4) All stations, except "#2 Right," yield patterns showing a characteristic tilt from left to right. (The AD end is thicker than the CF end.) This means that the leading end of the piece-part with respect to broaching direction is thicker than the trailing end. Such a phenomenon suggested that work-pieces were not securely held in place by the clamps but were being allowed to "rock" forward under load. Study of the timing and action of the clamping fingers was therefore indicated.

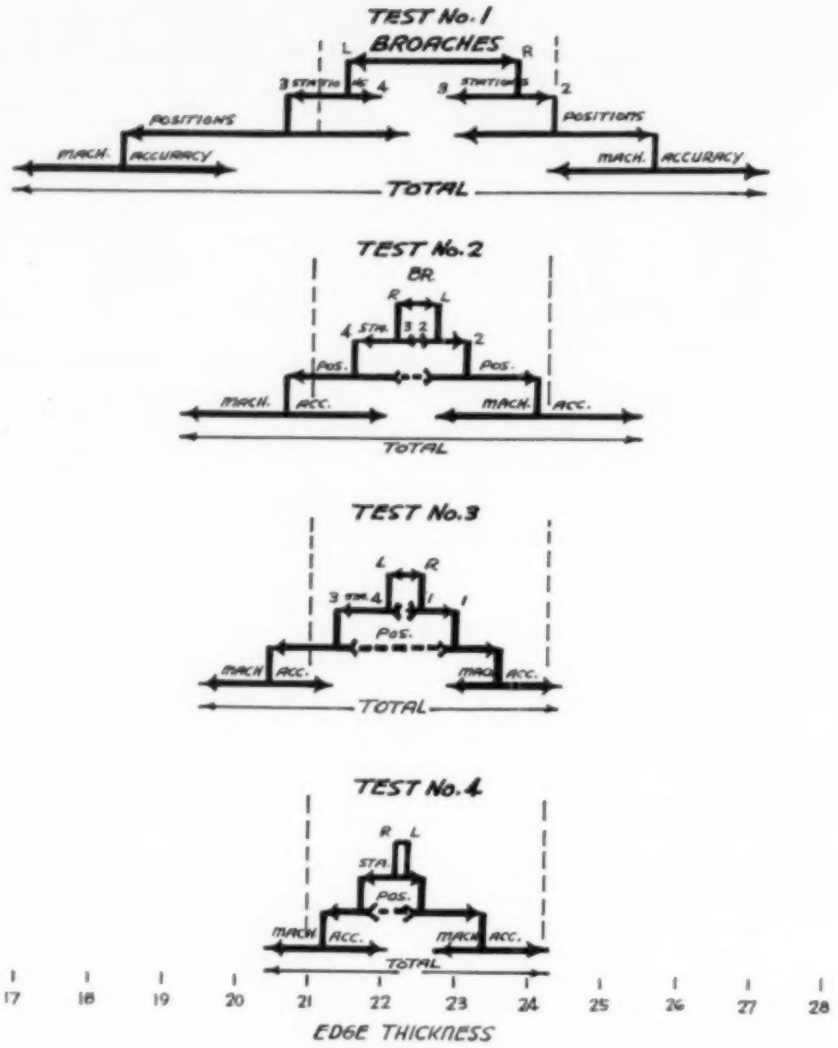

Figure 17—**Pictograms of Later Tests on Broaching Machine**

The results of these detailed analyses, together with the suggested actions, were transmitted to the broaching machine manufacturer. He questioned, as the unitiated well might, the ability to extract so many conclusions from so few test pieces. Fortified by the knowledge gained from the diagrams, however, the customer could confidently insist on their validity. Little time was wasted in argument, therefore, and the vendor proceeded with some of the suggested measures. The results were quite apparent when the second test run was made a few weeks later. Substantial improvements in Broach and Position effects were clearly evident, as shown in Figure 17. (The Station and Position vectors have begun to overlap in the second run; the amount of overlap is shown by the dotted line.)

The total variability was still too large, however, with respect to the tolerances required. With Broach and Position effects now considerably shrunk, the Machine Accuracy effect loomed as the next target. To this end, the design of work-stations and clamps was carefully reviewed and changes were incorporated to provide a closer nesting of the piece into the holder. This improved accuracy of piece-positioning led directly to the results obtained on Test Run #3.

Further diagnoses and actions later yielded Test Run #4, which brought the machine sufficiently within sight of its specified performance that the customer now agreed to accept delivery and seek further improvement after installation. He could confidently expect that few "bugs" would have to be "worked out;" for, by "diagnosing with diagrams," he had obtained the equivalent of a complete

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CONCLUSION

In conclusion, this paper has tried to show that ingenuity in constructing graphical representations of data really does pay off. It is certainly not the intent to imply that the particular diagrams shown will solve everybody's or even anybody's particular problems, although some of them are probably broader in scope than has yet been explored. The important point is that statistical data represented pictorially may get results where statistics alone may fail. To paraphrase the ancient Chinese proverb: "One picture in the hand is worth two sigmas in the bush."

Report of Standards Committee, ASQC

***Submitted November 28, 1949,* to Mr. Ralph E. Wareham, *President* ASQC**

The Standards Committee is pleased to submit herewith Proposed Standard Definitions and Symbols for Control Charts.

In approaching the subject of standard definitions and symbols such as might be used in the ASQC official publication, **Industrial Quality Control,** the Standards Committee felt it desirable to consider separately the terms used in different categories. The first subject chosen was Control Charts. The appended document covers this subject and has met with the unanimous approval of all members of the Standards Committee.

In accordance with its letter of instructions, dated October 1, 1947, from Mr. George D. Edwards, then president of ASQC, the Standards Committee understands that its duties may be summarized as follows:

"The Standards Committee is authorized to study and select those symbols, concepts, nomenclature, procedures, and other matters which it feels the Society would find advantage in standardizing and to make recommendations to the Board of Directors for such standardization by the Society."

Accordingly, the Standards Committee wishes to recommend to the Board of Directors that the proposed Standard Definitions and Symbols for Control Charts submitted herewith be standardized by the American Society for Quality Control.

ASQC STANDARDS COMMITTEE

E. L. Grant
R. E. Wareham
A. E. R. Westman
S. S. Wilks
H. F. Dodge, *Chairman*

Proposed

Standard Definitions and Symbols for Control Charts

TERM	SYMBOL	DEFINITION
1. GENERAL TERMS RELATING TO CONTROL CHARTS		
Unit		One of a number of similar items, objects, individuals, etc.
Variables		Measurement of quality by the method of variables consists in measuring and recording the numerical magnitude of a quality characteristic for each of the units in the group under consideration. This involves *reading a scale* of some kind.
Attributes		Measurement of quality by the method of attributes consists in noting the presence or absence of some attribute in each of the units in the group under consideration and *counting* how many do or do not possess it.
Universe		The total collection of units from a common source; the conceptual total collection of units from a process, such as a production process. Also used in the sense of a "universe of observations."
Sample		A group of units, taken from a larger collection of units, which serves to provide information that can be used as a basis for judging the quality of the larger collection, or as a basis for action on the larger collection or on the production process. Also used in the sense of a "sample of observations."
Assignable Cause		A factor contributing to the variation in quality that it is possible to identify.
Subgroup		One of a series of groups of observations obtained by subdividing a larger group of observations; alternatively, the data obtained from one of a series of samples taken from one or more universes.
Rational Subgroups		Subgroups *within* which variations may for engineering reasons be considered to be due to non-assignable chance causes only, but *between* which there may be variations due to assignable causes whose presence is considered possible. (One of the essential features of the control chart method is to break up inspection data into rational subgroups.)
Statistical Measure		A mathematical function of a set of numbers or observations. Common statistical measures are the arithmetic mean or average, the standard deviation, the range (for variables), and the relative frequency (for attributes).
Control Chart		A graphical chart with upper and lower control limits and plotted values of some statistical measure for a series of samples or subgroups. A central line is shown frequently.
Control Limits		Limits on a control chart which are used as criteria for action or for judging the significance of variations between samples or subgroups.
Central Line		A line on a control chart representing the average or expected value of the statistical measure being plotted.
Control Chart—No standard given		A control chart whose control limits are based on the data of the samples or subgroups for which values are plotted on the chart.
Control Chart—Standard given		A control chart whose control limits are based on adopted standard values of the statistical measure(s) for which values are plotted on the chart.
Sample Size	n	The number of units in a sample. Also used in the sense of the number of observations in a sample.

TERM	SYMBOL	DEFINITION
2. TERMS RELATING TO CONTROL CHARTS FOR VARIABLES		
(a) Statistical Measures		
Observed Value or Observation	X	The measured value of a quality characteristic for an individual unit; specific observed values are designated X_1, X_2, X_3, etc.
Average	$\bar{X}$ (X bar)	The arithmetic mean; the average of a set of n numbers, X_1, X_2, ... X_n, is the sum of the numbers divided by n; $\bar{X} = \frac{X_1 + X_2 + \ldots + X_n}{n}$
Standard Deviation	σ (sigma)	The standard deviation of a set of n numbers, X_1, X_2, . . . X_n, is the root-mean-square (r.m.s.) deviation of the numbers from their average: $\sigma = \sqrt{\frac{(X_1-\bar{X})^2 + (X_2-\bar{X})^2 + \ldots + (X_n-\bar{X})^2}{n}}$ or expressed in a form more convenient for computation purposes: $\sigma = \sqrt{\frac{X_1^2 + X_2^2 + \ldots + X_n^2}{n} - \bar{X}^2}$.
Range	R	The range of a set of n numbers is the difference between the largest number and the smallest number. (More precisely: the absolute value of the algebraic difference between the highest and lowest values.) R = (largest number) − (smallest number).
(b) Terms Relating to a Sample		
Sample Average	$\bar{X}$ (X bar)	The sum of the n observed values in a sample divided by n.
Sample Standard Deviation	σ (sigma)	The root-mean-square (r.m.s.) deviation of the observed values of a sample from their average.
Sample Range	R	The difference between the largest observed value and the smallest observed value in a sample.
(c) Other Terms		
Average value of $\bar{X}$, σ, or R	$\bar{\bar{X}}$, $\bar{\sigma}$, $\bar{R}$ (X double bar, sigma bar, R bar)	The average of the set of sample values of $\bar{X}$, σ or R under consideration. For samples of unequal size, a weighted average is used. These values are used in computing control limits for the case "No Standard Given."
Standard Value of $\bar{X}$ or σ	X', σ' (X bar prime, sigma prime)	The value of $\bar{X}$ or σ adopted as standard for computing control limits for the case "Standard Given." (These symbols are also used to designate the true or objective value of $\bar{X}$ or σ of the universe sampled.)
Factor for Central Line—Standard Deviation	c_2	A factor, varying with sample size n, that is equal to the ratio of the expected value of $\bar{\sigma}$ for samples of size n to the σ' of the universe sampled; $c_2 = \bar{\sigma}/\sigma'$. (Published values* are for a Normal universe.)
Factor for Central Line—Range	d_2	A factor, varying with sample size n, that is equal to the ratio of the expected value of $\bar{R}$ for samples of size n to the σ' of the universe sampled; $d_2 = R/\sigma'$. (Published values* are for a Normal universe.)
	$\sigma_{\bar{X}}$ σ_σ σ_R	The expected standard deviation of values of $\bar{X}$, σ and R for samples from a particular universe.

*ASTM Manual on Presentation of Data, p. 50, Am. Soc. Test. Mat'ls., Phila., 1944; also ASA Z1.3, Control Chart Method of Controlling Quality During Production, p. 39, Am. Stds. Assn., 1942.

TERM	SYMBOL	DEFINITION
3. TERMS RELATING TO CONTROL CHARTS FOR ATTRIBUTES		
(a) Statistical Measures		
Relative frequency, proportion	p	The ratio of the number of "events" to the number of "trials" under consideration, where only one "event" can occur per "trial." An "event" may be any kind of occurrence, a failure, a defective condition, etc. and a "trial" is a single instance of observing whether the event is present or absent.
	pn	The number of events, where only one event can occur per trial.
	u	The ratio of the number of events to the number of trials under consideration, where many events can occur per trial, and a trial is a unit area of opportunity for occurrence of the event. An example is number of pin holes per square foot; an event is the occurrence of a pinhole, a trial is the examination of one unit of area (1 sq. ft.), and the number of trials is the number of units of area (number of square feet) under consideration.
	c	The number of events, where many events can occur per trial. (See explanation accompanying definition of symbol u.)
(b) Terms Relating to a Sample		
Note: The following terms relate to events commonly called "defects" and "defectives" in quality control work. Other terms, such as failures, breaks, etc., can be substituted as necessary.		
Defect		A failure to meet a requirement imposed on a unit with respect to a single quality characteristic; also an irregularity in material, surface finish, etc.
A Defective		A defective unit; one containing one or more defects with respect to the quality characteristic(s) under consideration.
Sample Fraction Defective	p	The ratio of the number of defective units in a sample to the total number of units in the sample; the number of defectives in a sample of n units divided by n. Sometimes referred to as the sample "proportion defective."
Sample Number of Defectives	pn	The number of defectives in a sample of n units.
Sample Defects per Unit	u	The number of defects in a sample of n units divided by n; $u = c/n$.
Sample Number of Defects	c	The number of defects in a sample of n units.
(c) Other Terms		
Average Value of p, pn, u **or** c	$\bar{p}$ $\overline{pn}$ $\bar{u}$ $\bar{c}$	The average of the set of sample values of p, pn, u, or c. Values of $\bar{p}n$ and $\bar{c}$ may be computed for samples of equal size only. For a set of samples of unequal size, $\bar{p}$ and $\bar{u}$ are weighted averages, usually obtained as follows: $\bar{p}$ is the total number of defective units found in the set of samples divided by the total number of units in the set; $\bar{u}$ is the total number of defects in the set divided by the total number of units in the set. These values are used in computing control limits for the case "No Standard Given."
Standard Value of p, pn, u, **or** c	p' $p'n$ u' c'	The value of p, pn, u, or c adopted as a standard for computing control limits for the case "Standard Given." (These symbols are also used to designate the true or objective value of p,pn, u, or c for the universe sampled.)

TERM	SYMBOL	DEFINITION
	σ_p σ_{pn} σ_u σ_c	The expected standard deviation of values of p, pn, u, or c for samples from a particular universe. $\sigma_p = \sqrt{\bar{p}(1-\bar{p})/n}$ or $\sqrt{p'(1-p')/n}$ $\sigma_{pn} = \sqrt{\bar{p}n(1-\bar{p})}$ or $\sqrt{p'n(1-p')}$ $\sigma_u = \sqrt{\bar{u}/n}$ or $\sqrt{u'/n}$ $\sigma_c = \sqrt{\bar{c}}$ or $\sqrt{c'}$

Comments: The Standards Committee suggests that the above list of terms, definitions, and symbols relating to control charts be adopted as standard for ASQC purposes in order to conform with ASA and ASTM standards and with current usage in the quality control field. It further suggests that the following two departures from the standard be authorized as optional, the first offering some convenience in mathematical discussions in the control chart field, the second providing an alternative system of terms, definitions and symbols for the control chart for standard deviations which may appeal to members of the Society familiar with the concepts of analysis of variance. Should either of these departures from standard gain wide acceptance, they could be considered when a revision of the standard is in order.

(a) The standard uses the same symbol, for example, $\bar{X}'$, for both a standard value and a universe value. Where a distinction is desired, it is suggested that the following symbols be used:

$\bar{X}'$, σ' etc.—universe values.

$\bar{X}''$, σ'', etc.—standard values.

(b) For $\sigma = \sqrt{\frac{\Sigma(X-\bar{X})^2}{n}}$ substitute $s = \sqrt{\frac{\Sigma(X-\bar{X})^2}{n-1}}$ and for c_2 substitute c_s, where $c_s = c_2\sqrt{n/(n-1)}$ and n is the sample size. To avoid confusion between σ and s, the latter is to be called the "specific deviation," a new term now introduced for this purpose.

Note: "Specific deviation" might be considered as short for "root specific squared deviation" where "specific" might quite generally imply division by the number of degrees of freedom.

The Convention Takes Shape

"Meet me in Milwaukee" on June 1 and 2, 1950, at the Fourth Annual Convention and the Fifth Midwest Conference of the American Society for Quality Control is the desire of executives, production people, supervisors, inspectors, sales representatives, purchasing agents and other industrial personnel interested in Statistical Quality Control. In order to provide adequate facilities, the Milwaukee Auditorium has been reserved.

The Planning Committee, under the leadership of its Chairman, Mr. R. S. Saddoris, Director of Quality, A. O. Smith Corporation, Milwaukee, Wisconsin, has planned a most outstanding program—one which provides everyone in attendance something to take home. It is expected that this program will fully match the excellent programs of former conferences.

Plans are underway to have at least three main attractions: the educational sessions; the clinical sessions; and a series of demonstrations in connection with a large array of worthwhile exhibits.

The educational sessions, under the Chairmanship of Professor Edwin G. Olds, Carnegie Institute of Technology, are particularly designed to give executives and persons in a supervisory capacity a concise exposition of the philosophy and principles basic to Statistical Quality Control. In addition, the educational sessions will be very valuable to operators, foremen, and persons in clerical operations who have little or no knowledge of this modern scientific development, as well as to those who would welcome a review of the broad aspects of Statistical Quality Control—its aims and its purposes. This is an ambitious program and Dr. Olds has for his instructional staff Professors Irving W. Burr, Purdue University, C. C. Craig, University of Michigan, John A. Henry, University of Illinois, and Dr. Carl E. Noble, Kimberly-Clark Corporation. Each person on this outstanding staff has had much experience in such sessions and in training programs. It may be necessary to limit the attendance at the educational sessions to 400 persons.

The clinical sessions will be patterned after the successful arrangements at previous quality control conferences. Two sessions running concurrently are planned. In this way a person can select that particular session which will be of the greatest immediate help to him. Persons who are well known throughout the United States and Canada for their successful applications and technical knowledge have been invited to participate. A wide coverage has been attained in view of the fact that Messrs. Warren R. Purcell, Sylvania Electric Products, Inc., Salem, Massachusetts, and Stanley C. Amren, United States Time Corporation, Waterbury, Connecticut, from the east, and Professor Eugene L. Grant, Stanford University, from the west, have accepted invitations to speak.

A series of demonstrations in connection with an array of exhibits is somewhat of an innovation at a national convention of ASQC. Statistical Quality Control at Work! Arrangements are being made for each person at the conference to see this phase.

In addition to the general sessions, members of ASQC will want to attend the annual dinner meeting of the Society on Thursday evening, June 1, 1950.

No one will want to miss the luncheon on Friday, June 2nd. An officer of one of the world's largest companies will speak. It is expected that many business and industrial executives who may be unable to be present at other sessions will find time to attend this and the Friday afternoon sessions.

Quality Control personnel should make definite plans now to attend this convention, to invite and arrange for executives, supervisors, operators, and others within their organization to "meet us in Milwaukee," June 1 and 2, 1950.

The Quality Control Indicator

R. C. MILES

Refrigerator Quality Control Division
General Electric Company, Erie, Pennsylvania

IT IS A WELL-KNOWN FACT that the manufacture of a complicated assembly or mechanism in which no minor flaw can be found is virtually impossible and extremely expensive. The best that can be attained is to operate the process in statistical control at all times at a quality level which is regulated by the quality requirements of the customer and the cost of scrap and rework of defective parts or assembly. Quality characteristics of the "go, no-go" type may be analyzed automatically and continuously by the Quality Control Indicator; a signal is given the instant a characteristic is statistically out-of-control.

The Quality Control Indicator will be found useful and profitable in an extremely large number of applications throughout industry. Any manufacturer who inspects his product either in part or in whole to determine whether the part or assembly is good or bad has an application for the device. At present it is limited to processes producing 10% rejects or less, because it is felt that any process which produces over 10% defects is in need of basic changes, not quality control!

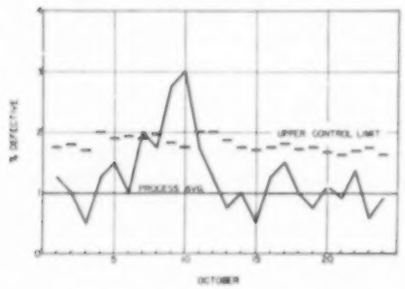

Figure 1—**Typical control chart for a quality characteristic with a process average of 1%. Points above the upper control limit signal the presence of manufacturing troubles.**

DISADVANTAGES OF MANUAL PLOTTING OF CONTROL CHARTS

The extent to which it will be practical to use control chart methods will be dictated by the cost of keeping control charts as compared to the savings accomplished by reducing the percent defective. There are three principal disadvantages to the use of the control chart methods.

1. Ideally, calculations should be made and analyzed each time a reject occurs. In most manufacturing operations this procedure will be found impractical from a manpower standpoint, and the best that can be obtained will be an analysis of each characteristic at the end of a period of time, usually a day or a shift. This delay in determining percentages which will fall outside control limits allows unnecessary rejects to be built before the out-of-control condition is known and action is taken to find and correct the trouble.

2. The actual trouble may have corrected itself by the time the out-of-control condition is known and no evidence of its existence will be available upon investigation. Experience has shown that troubles of this sort will occur again in the near future unless they are found and corrective action taken to prevent further occurrences.

3. Manpower is needed to collect data and analyze the percent rejects found to determine whether or not the process is in control.

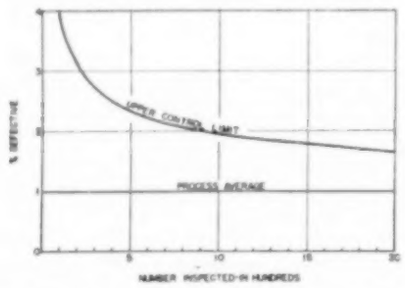

Figure 2—**Variation of upper control limit on a p chart with changes in sample size for 1% process average.**

BASIS OF AUTOMATIC CONTROL CHARTS

The problem of applying control chart methods to a large number of quality characteristics led to the building of the Quality Control Indicator, which performs automatically and continuously the principal functions of control charts of the type shown in Figure 1. The reject/production ratio is analyzed each time a reject occurs and a signal is given when the upper control limit is exceeded.

Unfortunately, the reject/production ratio applying to the upper control limit is not a direct ratio. Figure 2 shows the relation of the upper control limit (in percent defective) to production for a process average of 1%. It will be noted that the

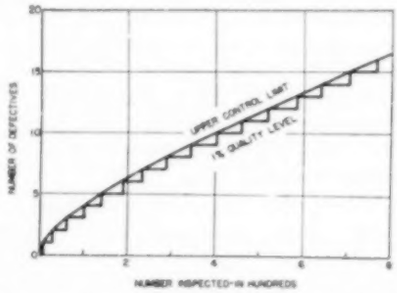

Figure 3—**Variation of upper control limit on a pn chart with changes in sample size for 1% process average.**

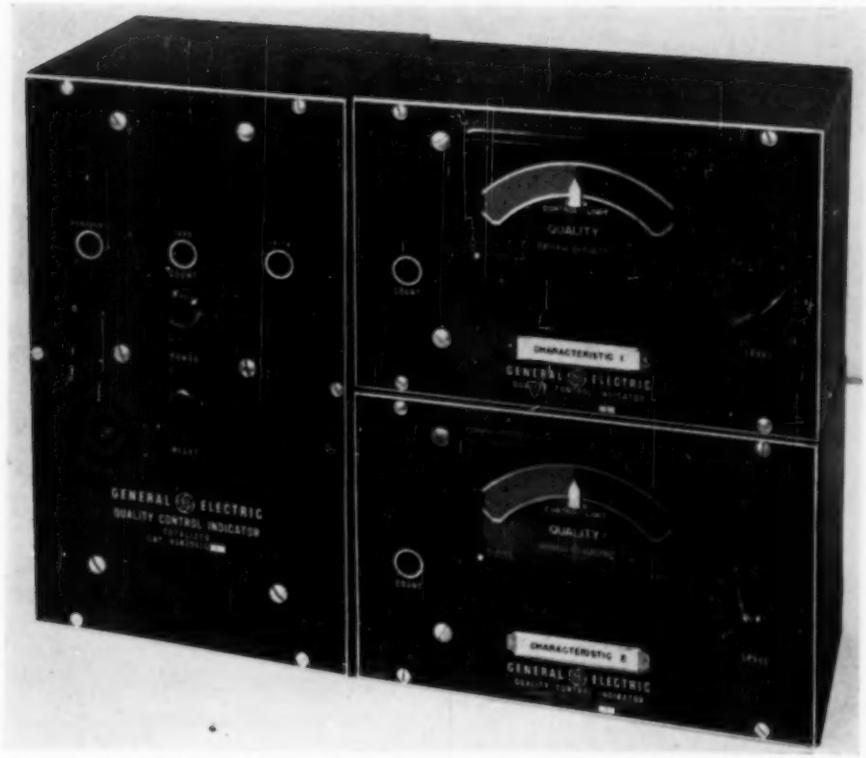

Figure 4—*QUALITY CONTROL INDICATOR USING ONE TOTALIZER AND TWO CHARACTERISTIC ANALYZERS.*

upper control limit is far above the process average when the production is small, and is close to the process average when the production is large. This condition is accounted for by the nature of sampling fluctuations, i.e., the larger the sample, the narrower the band within which sampling variations may be expected to lie.

The reject/production ratio for the upper control limit may also be plotted with the ordinate scale showing "number of defectives." Such a chart for a process average of 1% is shown in Figure 3. This curve provides the basic information needed for the design of the Quality Control Indicator. The step curve in Figure 3 is drawn to provide a working basis since only whole rejects are dealt with.

It should be noted that the curves shown in Figure 3 are calculated and plotted for only a 1% level; the Quality Control Indicator is designed to follow any similar curve between 0 and 10%.

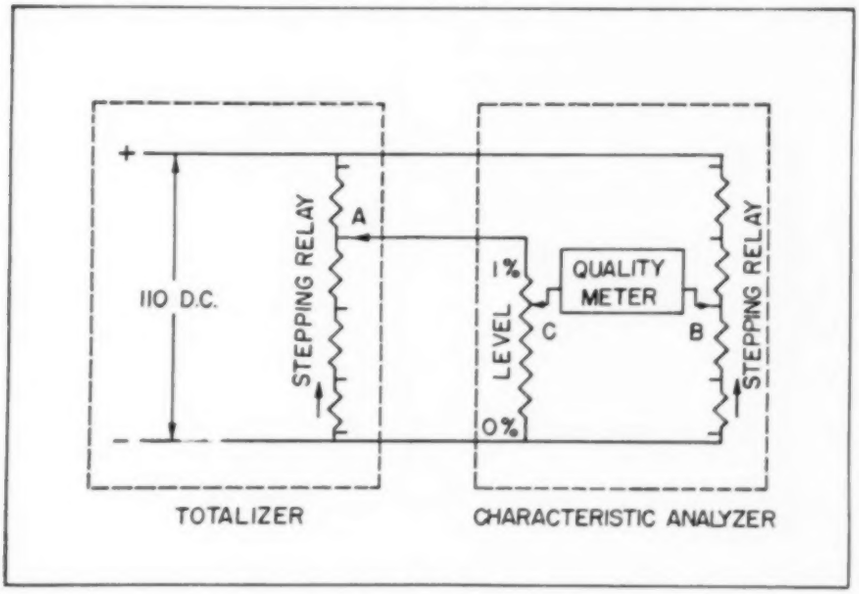

Figure 5—*SCHEMATIC DIAGRAM OF CIRCUITS IN TOTALIZER AND CHARACTERISTIC ANALYZER.*

ELECTRO-MECHANICAL CONSTRUCTION

The Quality Control Indicator is pictured in Figure 4. It has two basic parts; the Totalizer, which counts the number of inspected parts or production, and the Characteristic Analyzer, which counts the number of rejects for one quality characteristic and relates that number to the upper control limit for the production at that time as indicated by the Totalizer. The counting is accomplished by means of solenoid operated rotary stepping relays. The Totalizer solenoid is impulsed by closing a set of contacts each time a unit is inspected; the Characteristic Analyzer solenoid is impulsed by closing another set of contacts each time a reject is found.

The counting operation of the stepping relays is both mechanical and electrical. A numbered dial attached to the shaft of the relay, shows the count of units inspected through an escutcheon on the front panel of the Totalizer; the count of rejects is shown by a similar arrangement on each Characteristic Analyzer. Figure 5 shows the Electrical circuits schematically. The circuit between the stepping relay contacts operates as a voltage divider. A voltage applied to the end contacts of each stepping relay is divided by means of resistors wired in series to all stationary contacts. The rotary contacts A and B will pick off a different voltage at each step. The voltage between A and (-)d.c. is divided by a potentiometer to provide an adjustment of quality level between 0 and 10%. The voltage at the movable contact C on the quality level potentiometer is compared with the voltage at B simply by measuring the current which flows between B and C. The meter chosen to measure the current flowing between B and C is a rugged type in which the needle stands at mid-scale when no current is present (equal voltages at B and C). If the voltage at B exceeds that at

C, current flows through the meter in one direction and the needle deflects to the right in proportion to the voltage difference.

The proper resistance values are selected for the voltage dividers and the level potentiometer so that the meter needle will be at mid-scale when the reject/production ratio, as reflected by the stepping relays, is on the upper control limit. If the upper control limit is exceeded, the meter needle deflects to the right into the red half of the scale in proportion to the amount the control limit is exceeded; if the reject/production ratio is below the upper control limit, the needle deflects to the left into the green half of the scale.

Since the meter here discussed shows the reject/production ratio at all times, it may be rightly called a Quality Meter. A vertical line at mid-scale is labeled "Upper Control Limit." The red area to the right of mid-scale signals the presence of trouble which needs attention, while the green area to the left of mid-scale indicates normal conditions. In operation, the needle will start at mid-scale when the reset button is pushed (at start of production) and progress to the left in small increments with production count fed to the Totalizer. When rejects occur, the needle moves in large increments to the right so that there will never be any doubt as to whether the needle is above or below the upper control limit.

AN INSTALLATION OF QUALITY CONTROL INDICATORS FOR CONTROLLING 24 QUALITY CHARACTERISTICS ON 4 PRODUCTION LINES.

EPIDEMIC CONTROL

The question of controlling epidemics which may occur near the end of a shift has been the subject for many discussions, relative to the ideal Quality Control Indicator. For example, it would be possible to have a process which produced far less rejects than the upper control limit allows for, perhaps, the first 1,600 units produced. With this condition a large number of rejects would be required to exceed the upper control limit, and, if those rejects did occur, a temporary out-of-control condition could exist without causing the needle of the Quality Meter to exceed the upper control limit line.

In the light of practical experience, the epidemic control problem has become relatively minor for three reasons. First, such cases would happen only rarely; a year's experience with the Quality Control Indicator revealed no need for an epidemic control. Second, the worst condition that could exist would be the occurrence of a percent defective near the upper control limit for the operating period, (day, shift, etc.). No real basis for alarm is indicated since the maximum number of defectives allowed is still controlled. Third, if the Quality Meter is observed, the needle will be seen to advance rapidly toward the red during the epidemic. A trained observer will investigate such a case.

SUMMARY OF FEATURES

The Quality Control Indicator has the following features:

1. Two models are available and interchangeable. The first operates at any quality level between 0 and 1%; the second operates at any quality level between 0 and 10%. Level may be set readily by a control knob on the front panel of each Characteristic Analyzer.
2. A total production of 2,000 units can be analyzed without resetting.
3. A process out-of-control condition is indicated when the needle on the Quality Meter is at mid-scale or in the red portion.
4. The indicator is accurate to within one reject of the true allowable number at all times.
5. From one to ten Characteristic Analyzers may be used with each Totalizer.
6. A reset button is provided on each Totalizer to zero that unit and all attached Characteristic Analyzer units at any time. For example, at the end of a day, shift, etc.
7. An accurate count of total units produced is indicated on the front panel of the Totalizer.
8. A count of rejects for each quality characteristic is available at the front panel of each Characteristic Analyzer.
9. The counters are attached to the stepping relays and are automatically zeroed when the device is reset.
10. The Totalizer cabinet is 12" x 7" x 6"; the Characteristic Analyzer cabinet is 6" x 8" x 5". These cabinet sizes were chosen to provide ease of stacking and a neat appearing installation.
11. The required power supply is 110 volts a.c. or d.c.

INSTALLATION IN THE FACTORY

The method of installing indicators in the factory will vary with the nature and number of characteristics to be controlled. In general, it will be necessary to have one Totalizer for each conveyor or production

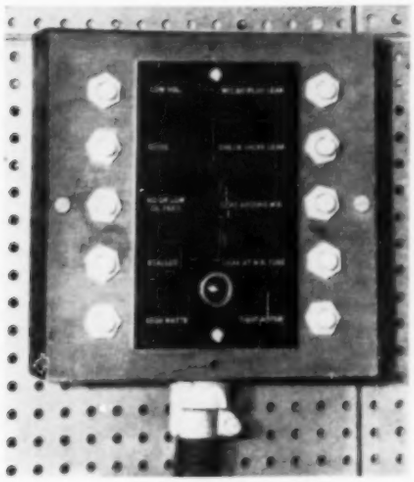

Figure 6—**Typical switch box used by inspector to energize appropriate Characteristic Analyzer solenoid when a reject occurs.**

line and one Characteristic Analyzer associated with each Totalizer for each quality characteristic to be controlled. The unit type construction was decided upon to make it possible to install the exact number of Characteristic Analyzers needed with each Totalizer. The necessary wiring between units is accomplished by plug-in cables at rear of cabinets.

Figure 4 shows the units needed to control two quality characteristics, which apply to one part or assembly produced on one production line. The location of the Characteristic Analyzers is very important; the Quality Meters will serve their purpose best if they can be observed easily.

In the ideal installation, the count of production will be supplied to the Totalizer by a set of contacts, which close automatically each time a part or assembly enters an inspection station. If the inspection is automatic, a similar arrangement can be used to supply the count of rejects to each Characteristic Analyzer.

Snap action switches are employed where manual counting is used; this eliminates the possibility of the operator making a double count. Figure 6 shows a typical reject switch box which is used at an inspection station. Ten quality characteristics are checked at this point and the appropriate switch button is pushed each time a reject is found.

THE CONTROL OF QUALITY

Once the Totalizer units and Characteristic Analyzers are installed, together with the necessary equipment to feed in units produced and rejects found, the control of quality is greatly simplified. Each Characteristic Analyzer is set to operate at the quality level which applies and the Quality Control Indicator becomes the watch-dog over quality. Each Quality Meter shows continuously the quality story for that characteristic. Normally, there would be no need for investigation as long as the needle is to the left of mid-scale in the green area. Should a needle move into the red portion, an immediate investigation is made.

It is possible also to observe relative quality by noting the deflection of the needles. A needle which is far to the left end of the scale indicates very good quality; a needle which is shifting towards mid-scale indicates a possible epidemic of trouble, and, of course, the farther the needle moves into the red the worse the trouble is.

The convenience of the counters is particularly noticeable. The production figures together with the counts of various rejects are read directly at the control station, rather than from various counters on the line and inspectors' tally sheets. The keeping of records is thereby greatly simplified.

Experience to date with the Quality Control Indicator has shown that in virtually all cases of an out-of-control indication, the cause was found at that time and corrective

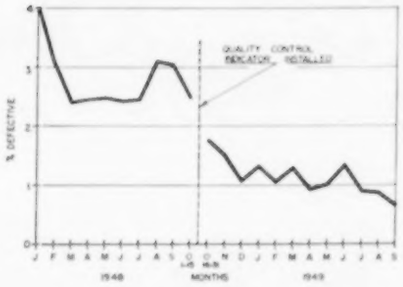

Figure 7—**Total percent rejects for 5 quality characteristics before and after installation of Quality Control Indicator. First day of controlled operation was October 16, 1948.**

action was taken immediately. The results of the first installation of a Quality Control Indicator are reported in Figure 7. Five quality characteristics were controlled. A reduction in percent rejects was noticeable from the start. The percent rejects declined steadily until it stabilized at an average process level which was approximately 40% of the level previously held. The reduction in rejects was brought about solely through the combination of out-of-control signals from the indicator and corrective action by the manufacturing supervisors. The quality control engineers adopted a "hands off" policy as soon as the installation was complete.

The following points summarize the advantages obtained by using the Quality Control Indicator:

1. The device is invaluable to factory supervision because it provides automatically a running record of quality and points out troubles at the earliest possible moment.

2. Guess-work is eliminated and supervisors' time for trouble-shooting is utilized with high efficiency.

3. The percent of rejects is markedly reduced, thereby improving product quality and materially reducing scrap and re-work expenses.

The May Issue of Industrial Quality Control Will Be the

CONVENTION ISSUE

It will be BIG! **Watch for it!**

A Simple Calculator for Averages and Ranges

A. R. BURGESS

Agricultural and Mechanical College of Texas

IN MAKING a control chart for variables, it is necessary to compute the average and the range of samples taken from the production process. These calculations are, of course, very simple, but when they must be performed repeatedly, they are time consuming and subject to the personal error common to all arithmetic operations.

There are, however, two characteristic features of most control charts for variables which make practical another approach to this problem. The first of these is the fact that the sample size used is very often either 4 or 5 pieces, since these two choices strike a nice balance between amount of inspection and value of the information obtained in the sample. The other feature is that the variation in the observed property being charted is usually small, occurring generally in the last two digits only.

It will be recalled that if a variable X has the values X_1, X_2, X_3 . . . X_n, the average of this series of n values of X can be readily obtained by assuming some arbitrary value X_o, and then using the relationship $\bar{X} = X_o + \Sigma(X - X_o)/n$. If the variation in X is relatively small, it is possible to choose X_o so that all of the deviations $X - X_o$ will be small, and summing them is a simple matter. In some cases it is easy to do this mentally, especially if $X - X_o$ is seldom over ten.

However, it may be more convenient to perform these additions mechanically, since they are usually confined to relatively small deviations. A simple way of accomplishing such mechanical addition is to employ a circular disk with uniformly spaced perforations near its outer edge. If such a perforated disk is placed on top of a slightly larger disk having numbers spaced the same as the perforations, and a pivot put in the center, we have a simple "gadget" for summing the $X - X_o$ deviations, without actually having to compute them.

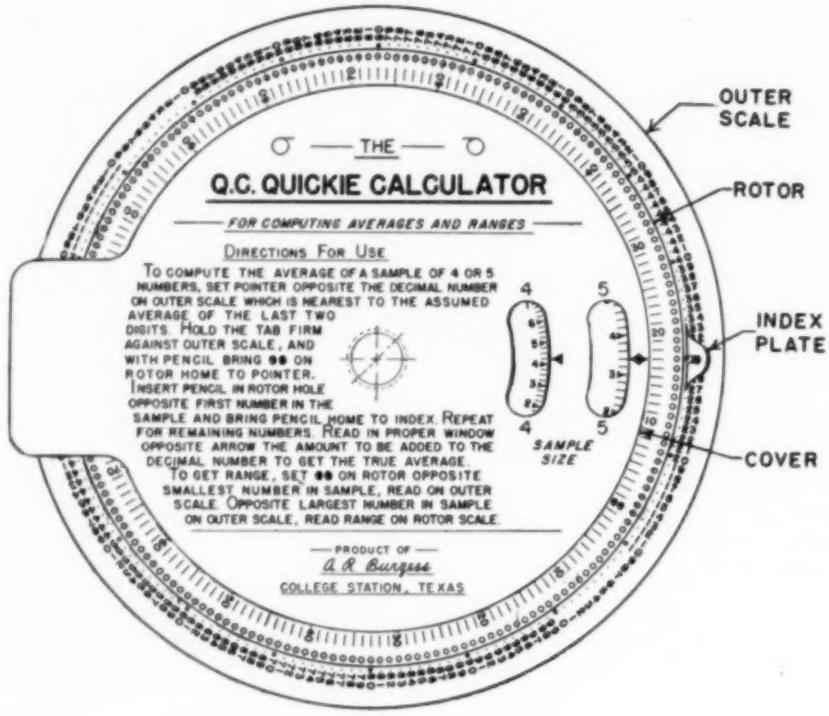
OUTER SCALE
ROTOR
INDEX PLATE
COVER
— THE —
Q.C. QUICKIE CALCULATOR
FOR COMPUTING AVERAGES AND RANGES
DIRECTIONS FOR USE
TO COMPUTE THE AVERAGE OF A SAMPLE OF 4 OR 5 NUMBERS, SET POINTER OPPOSITE THE DECIMAL NUMBER ON OUTER SCALE WHICH IS NEAREST TO THE ASSUMED AVERAGE OF THE LAST TWO DIGITS. HOLD THE TAB FIRM AGAINST OUTER SCALE, AND WITH PENCIL BRING ●● ON ROTOR HOME TO POINTER. INSERT PENCIL IN ROTOR HOLE OPPOSITE FIRST NUMBER IN THE SAMPLE AND BRING PENCIL HOME TO INDEX. REPEAT FOR REMAINING NUMBERS. READ IN PROPER WINDOW OPPOSITE ARROW THE AMOUNT TO BE ADDED TO THE DECIMAL NUMBER TO GET THE TRUE AVERAGE.
TO GET RANGE, SET ●● ON ROTOR OPPOSITE SMALLEST NUMBER IN SAMPLE. READ ON OUTER SCALE. OPPOSITE LARGEST NUMBER IN SAMPLE ON OUTER SCALE, READ RANGE ON ROTOR SCALE.
4
5
SAMPLE SIZE
— PRODUCT OF —
A R Burgess
COLLEGE STATION, TEXAS

Figure 1

One more step makes the device especially adapted to control chart work. If n is likely to be either 4 or 5, then we can put concentric scales on the rotating perforated disk which will be one-fourth and one-fifth respectively of the scale of the perforations, and this will divide $\Sigma(X - X_o)$ by n to give the amount to be added to X_o to get the true $\bar{X}$ for the sample.

Figure 1 shows a simple calculator based on the above approach. The outside scale of this calculator is on the bottom disk, which is numbered from 0 to 100 twice around its perimeter, making a total of 200 numbers. 200 is chosen as the practical upper limit because the size of the numbers and the space between them would make a prohibitively large device if more were used. It is also used as the lower limit because it is desirable to have a number which is divisible by 4, 5, and 10, so that the inner scales come out even.

Since it is necessary to have some way of stopping the rotation of the perforated rotor at the chosen value of X_o, an index plate is provided which has a small slot cut in it. In use, this slot is set at the chosen value of X_o, and since the index plate with its slot lies under the rotor, it follows that when a pencil is placed in one of the perforations and the rotor turned with it, the pencil point drops down in the slot at X_o.

Finally, there must be some means of reading the position of the rotor, especially on the inner divisor scales, after the summation has been made, so a cover plate is provided which carries arrows to point to the inner scales. This cover plate is tied in to the index plate, and moves with it

when the latter is being set at X_o.

To use the calculator, we proceed as follows:

1. The outer scale is held and the index plate slot is set at X_o, which for convenience is taken as a number ending in 0, preferably just slightly less than the estimated average.

2. The rotor is zeroed by bringing the •• to the slot with the point of a pencil.

3. A pencil is placed in the rotor perforation opposite the first value of X, read on the outer scale, and the rotor turned with the pencil until the pencil point is stopped by the slot. This is repeated for the other values of X.

4. In the appropriate window, read the amount to add to X_o to get $\overline{X}$.

If the assumed value of X_o was not more than 10 units less than the true $\overline{X}$, the amount in the window is added directly. For example, in the illustration of the calculator shown in Figure 1, the answer would be read as 33.4 if the sample size had been 5, since the slot in the index is set at an X_o of 30, and the arrow points to 3.4 in the window for that sample size. If the estimate was not that close, there is shown in the window that another 10 must be added, or perhaps 10 or 20 subtracted if the estimate was high. If the original estimate was too wild, then the capacity of the device has been exceeded in that the $\Sigma(X - X_o)$ result may be more than one-half revolution of the rotor, i.e., 100 units, and an extra revolution of the rotor will give a misleading answer. This is not a serious problem, since it is no trick to estimate X_o within plus or minus 20 units when the variation is only in the last two digits.

If the calculator is used on the same variable repeatedly, it is seldom necessary to reset the value of X_o, which of course facilitates its operation.

Although this device is designed primarily for the calculation of averages of samples of 4 or 5, a number of other things can be done with it. For example, it can be used to get the average of any series of numbers that vary only in the last two digits if one is willing to perform the slight extra chore of dividing the $\Sigma(X - X_o)$ by n. To show the value of $\Sigma(X - X_o)$, a scale has been put on the rotor reading from plus 100 to minus 100 on either side of the •• origin. A typical application of this sort of problem is the calculation of $\overline{R}$ for a series of samples, and of $\overline{X}$.

The calculator is made of a plastic material, and measures 6¾″ in diameter. It works best with an automatic pencil using a standard thickness, medium lead. A set of instructions, more complete than those on the face of the calculator, is being prepared which will also describe a variety of other calculations that may be made with it.

It is believed that this device may be of considerable help to the individual who has a great many points to plot on the control chart for averages. Furthermore, since one of the chief objections frequently raised against the installation of a control chart on a job is the complaint about time wasted in "non-productive" figuring and recording, it is hoped that this device may help the quality control engineer in introducing control methods by minimizing the amount of arithmetic to be done.

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The Pocket Comparator

A New Measuring Instrument

DESCRIPTION

The Pocket Comparator is a high-precision optical measuring instrument for the inspection of small parts or small dimensions on large parts. It fulfills the long-standing and widespread need for a multi-purpose inspection instrument. Heretofore, it has always been necessary to use a different device for checking linear measurements, circles, angles, radii, etc. Now, at last, there is one instrument that performs all of these inspection functions. The Pocket Comparator is not only a new instrument, but embodies a new principle by permitting the user to compare, through a magnifying lens, the part to be checked against a finely calibrated pattern or reticle. The lens is a triplet-design aplanatic type of great accuracy and has a magnification of approximately 7 to 1. The instrument was developed and is manufactured by Bell and Howell Company and is distributed by National Tool Company, Cleveland, Ohio.

The reticle of the Pocket Comparator is calibrated for measuring lengths, widths, complete circles, radii and angles. The upper part of the reticle has lengths graduated in steps of 1/64", 1/32", 3/64", 3/32", 1/8", 3/16" and 1/4". There is also a linear rule of 1/2" with .005" increments, and a 10 mm linear rule with .2 mm increments. Circles are shown graduated from .002" to .050" diameter and from 1/64" to 1/16" diameter. The lower half of the reticle is patterned to measure angles between 0 and 90 degrees in steps of 5 degrees, and to measure radii from 1/16" to 3/8".

The Pocket Comparator separates in the middle for two purposes: the first is to permit cleaning the interior optical surfaces; the second, for adjustment of focal length to meet the eye requirements of the individual using the instrument. Transparent, plastic material is used between lens and reticle to permit the entrance of light on the reticle and work to be measured.

APPLICATIONS

Although the instrument is brand new to industry, Bell and Howell, manufacturer of the Pocket Comparator, has been using it extensively for five years. Consequently, it has been thoroughly tested in the following applications.

Tool Room Use:

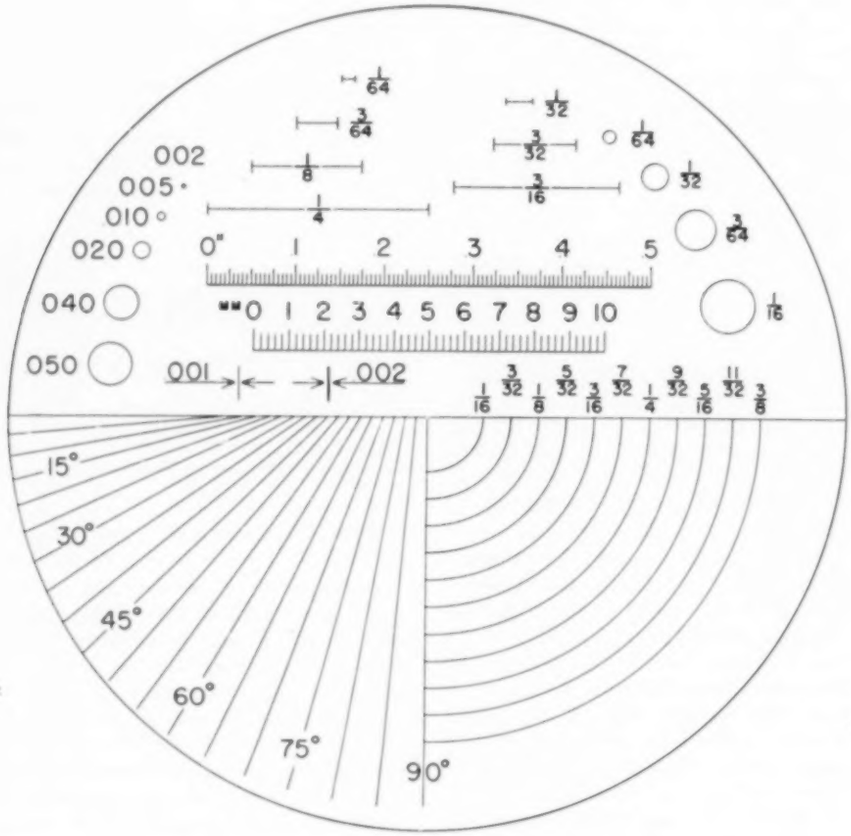
For checking forms and sizes of punches and dies.

For checking gauges, templates and layouts.

For checking the forms and dimensions of all types of cutting tools.

For checking the amount of wear on the cutting edges of all types of

A



B

cutting tools, punches, etc.

For checking the ground form on conventional tool bits.

For checking the form on circular and flat form tools.

For checking the size of small holes, fine threads and wires.

Production Checking:

The Pocket Comparator can be used for checking radii, angles, chamfers, threads, small holes, lineal, radial and tangent dimensions, odd shapes, etc. on machined, stamped or cast production parts. In many cases parts can now be checked on the production line rather than being taken to large stationary inspection machines, thus saving handling time.

The Pocket Comparator can also be used for the establishment of standards and the inspection of bubbles, blow holes, cracks or other flaws in die castings, plastic molded parts, glass parts, and others such as lenses or jewels.

General Use:

The Pocket Comparator has not been used as yet except by Bell and Howell, but should find ready acceptance in many totally unrelated fields. Some suggested applications are:

Jewelry manufacturers, in checking jewels, size, grade, form, flaws, etc.

General inspection use, for engravers, type founders, etc.

Die casting and plastic molding.

For printers and artists.

For metallurgists, chemists and general laboratory work.

For textile work and paper manufacturing, for checking grades and flaws.

For abrasive work, to check grain size and shape.

For general use in home workshops.

The accompanying photograph shows:

A. The Pocket Comparator—new multi-purpose inspection instrument.

B. The reticle or pattern of the Pocket Comparator is optically polished crown glass—hard enough to stand years of normal usage.

A New Slide Rule for SQC Calculations

A NEW slide rule for SQC calculations has been designed* and is now available. This rule has all scales ordinarily found on a log log slide rule. In addition it has scales for the constants used in calculations of limits for charts for measurements and for percent defective, as well as ordinates and areas of the normal curve. These special scales aid in calculation of the following:

1—Control limits for charts for measurements.

Constants for charts for measurements include those to calculate limits for averages, ranges, standard deviations, and individual values. Scales are included to find 3 sigma values and for k sigma values if some number other than 3 is desired. These constants are equivalent to a table such as that found in American Standards Association, Z 1.3-1942. The scales are arranged so that the constants are in convenient position to multiply by the appropriate quantities. Scales are included to estimate population standard deviation from average range or average standard devitaion of samples.

2—Control limits for chart for percent defective.

One scale is used to find limits for percent defective and related charts. The amount to be added to and subtracted from the central value for 3 sigma limits is found by one setting of the rule. From this value, limits for pn charts or for k sigma limits may be found.

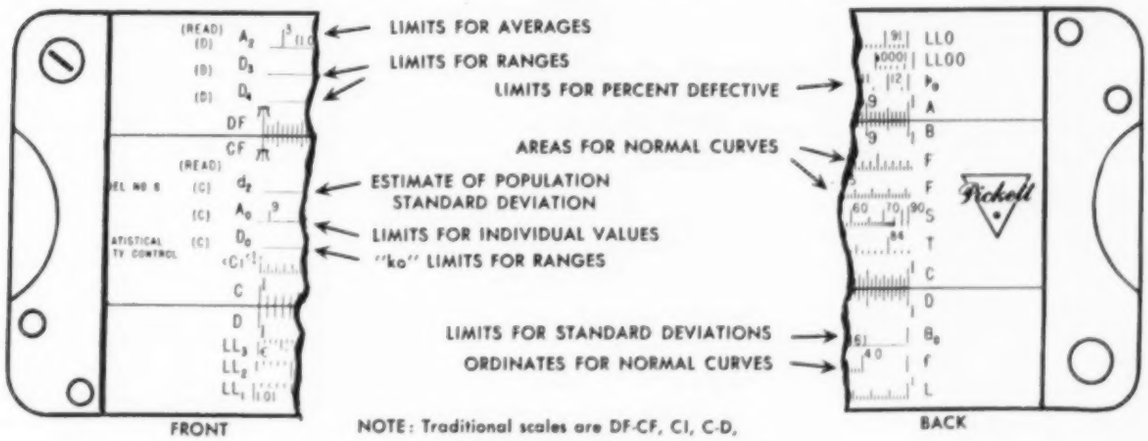
3—Ordinates and areas of the normal curve.

Another set of scales is used to find areas and ordinates for the normal curve. These scales are related to the log log scales, so that near two or three standard deviations from the mean, four or five decimal places may be read.

Most of the problems arising in quality control can be solved by means of this rule, and since it includes the constants needed and val-

*The quality control features of this instrument were designed by John M. Howell, California Section, ASQC.

QUALITY CONTROL SLIDE RULE



NOTE: Traditional scales are DF-CF, CI, C-D, LL_1, LL_2, LL_3, LLO, LLOO, A-B, S, T, C-D, L.

ues for the normal curve, it makes it unnecessary to carry a table of constants and tables of the normal curve.

This duplex-type quality control rule is 12½" × 2" × 5/32" in size. Weighs less than 4 ounces. Nonwarping light-metal core with optical tongues and grooves insure permanent alignment, freedom from distortion, easy operation. Needle-sharp graduations coordinate front and back. Made by Pickett & Eckel, Inc., Chicago, Illinois.

Bibliography

JOSEPH MOVSHIN, Editor

Assisted by the Editorial Committee, St. Louis Section, ASQC

On matters concerning the Bibliography Department, send correspondence, suggestions, and contributions to: Mr. Joseph Movshin, 9220 Old Bonhomme Road, St. Louis 24, Mo.

APPLICATION—AUTOMOTIVE INDUSTRY

QUALITY CONTROL PROGRAM AT REO REDUCES COSTS, Julian K. Miller, Director of Quality Control, Reo Motors, Inc.

(Automotive Industries, v. 101, n. 6, Sept. 15, 1949) General quality control application and values thereof.

APPLICATION—CHEMICAL INDUSTRY

STATISTICS APPLIED TO ANALYSIS, Grant Wernimont, Eastman Kodak Co., Rochester, N. Y.

(Analytical Chemistry, v. 21, n. 1, Jan. 1949)

A great many specific references are given in this paper on the uses of various statistical quality control methods as applied to chemical problems. Among those techniques discussed are: frequency distributions, control charts, variance analysis, correlation, sampling, and the design of experiments. This article contains a bibliography of 134 references.

QUALITY CONTROL OPPORTUNITIES FOR CHEMISTS, K. C. Longman.

(Chemical & Engineering News, v. 27, n. 47, Nov. 21, 1949)

Such problems as: acceptance of raw material, control and use of materials, how, where and what properties should be tested and how often, are examples of major chemical industry problems. These and others can be approached by quality control for a working solution. Uniformity and conformity in finished products can also be controlled. Quality control further provides a means of quickly tracing down causes of poor quality.

APPLICATION—ELECTRICAL INDUSTRY

SAVING TIME IN TESTING LIFE, W. R. Purcell, Manager of Quality Control, Sylvania Electric Products, Inc., Salem, Mass.

(Electrical Engineering, v. 68, n. 7 July, 1949)

Considerable technical quality control data for the use of median and minimum control charts are provided. This application of the median and minimum control chart is to accelerated life tests of incandescent lamps. (See also an earlier paper by the author on this subject in Industrial Quality Control, v. 3, n. 5, March, 1947.)

AN OVERALL INSPECTION PROGRAM, Henry M. Wolfson, Asst. Superintendent of Inspection, Western Electric Co., Haverhill, Mass.

(Electrical Engineering, v. 68, n. 7, July, 1949)

In general terms this article discusses the use of standard sampling plans (such as the Dodge and Romig plans) in the manufacturing of transformers and other electrical coil equipment. This production includes a large variety of types and requirements and a corresponding diversity of inspection and quality control procedure is used.

APPLICATION—MEDICAL & DRUG INDUSTRY

THE SEQUENTIAL ANALYSIS OF BLOOD PRESSURE SCORES, Jack Mashman, Statistician, Office of Research and Medicine, U. S. Atomic Energy Commission, Oak Ridge, Tennessee.

(Industrial Medicine & Surgery, v. 18, n. 8, Aug. 1949)

An application of the sequential analysis techniques of Professor A. Wald, Columbia University.

APPLICATION—METALLURGICAL INDUSTRY

OPERATION OF STATISTICAL QUALITY CONTROL IN A STEEL MILL, W. T. Rogers, Metallurgical Statistician, National Tube Co., Lorain Works, Lorain, O.

(Steel, v. 124, n. 11, March 14, 1949)

This quite extensive article shows the use of various statistical techniques in a large steel mill.

Examples are given to show the use of p charts, frequency distributions, $\bar{X}$ & R charts, "t" test, analysis of variance, moving average, multiple correlation, sampling. There are numerous charts and tables illustrating the various techniques.

APPLICATION—METAL WORKING

PREDICTING MACHINE CAPABILITY, Dorian Shainin, Chief Inspector, Hamilton Standard Propellers.

(Machine Design, v. 22, n. 1, Jan. 1950)

The use of the average and range chart in analysing natural process capability is discussed as a means of predicting the level of machine performance. An outline is provided as a guide to finding assignable causes of machine variation. Examples of the detection and correction of

such assignable causes of machine variation are given.

PITTSBURGH FORGINGS COMPANY—A STUDY IN PROGRESS, John C. McComb. (Section on "Inspection Department")
(Steel Processing, v. 35, n. 9, Sept. 1949)

A very brief, one-page outline of the use of inspection and quality control in the production of forgings.

ENGINEERING & EXPERIMENTS

HOW CHANCE LAWS CUT PRODUCTION COSTS, (Based on a paper by Dorian Shainin, Chief Inspector, Hamilton Standard Propellers)
(Aviation Week, v. 50, n. 17, April 25, 1949)

A general descriptive discussion of quality control with emphasis on the statistical setting of tolerance. A nomogram for combining tolerances statistically is given and explained.

PROBABILITY METHODS FOR ESTABLISHING TOLERANCES, M. D. Barrows, General Electric Company.
(Product Engineering, v. 20, n. 11, Nov. 1949)

The use of probability distributions in establishing tolerances for total dimensions that are the results of combinations of basic part dimensions.

MANAGEMENT & PERSONNEL

WATCH YOUR CUSTOMERS' COMPLAINTS, Wm. A. MacCrehan, College of Engineering, N. Y. U.
(American Machinist, v. 93, n. 13, June 30, 1949)

Explains a system of recording and investigating customer complaints. Illustrations of data sheets and computations are included. Time lag between production and complaint is discussed.

TRAINING SUPERVISORS IN QUALITY CONTROL, (Editorial Staff)
(Management Review, v. 38, n. 5, May, 1949)

¼ page—results of a Cleveland survey on plant training for quality control.

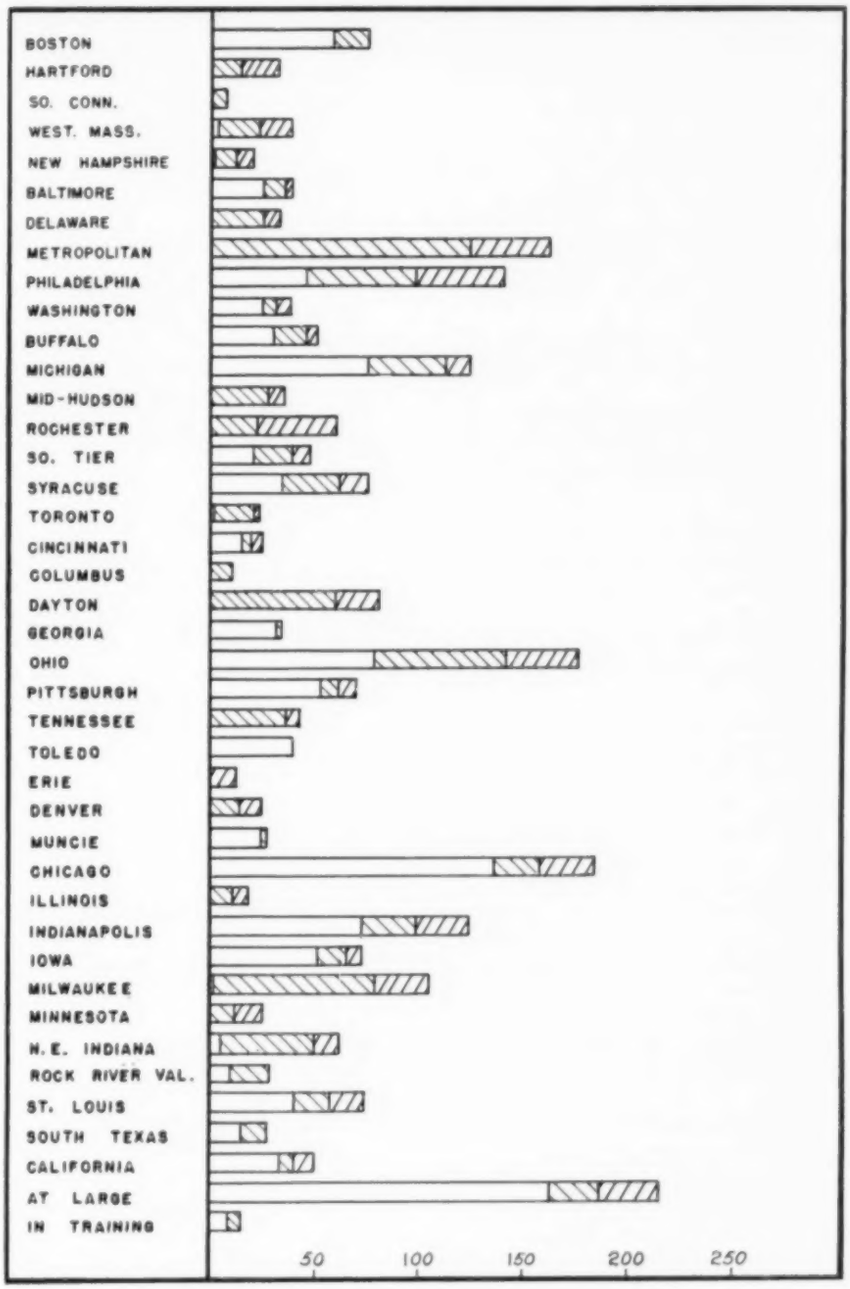
DELAY ALLOWANCES BY STATISTICAL METHODS, Adam Abruzzi, Columbia University.
(Columbia Engineering Quarterly, v. 1, n. 1, May, 1948)

Use of the p chart for estimating the proportion of delays in time study and methods analysis work.

THE QUALITY OF OFFICE WORK CAN BE CONTROLLED, William R. Rivine and Harvey Sherman.
(Management Review, v. 33, n. 9, Sept. 1949)

General discussion of the value of quality control as a means of controlling quality of office work.

BAR-CHART OF PAID-UP ASQC MEMBERS PER SECTION AS OF JANUARY 23, 1950



Total ASQC Membership January 23: 2559

MISCELLANEOUS

INTEGRATED QUALITY CONTROL—MAKES POSSIBLE LARGE SCALE PRODUCTION OF PRECISION BEARINGS, Walter F. Toerge, Associate Editor, Steel.
(Steel, v. 125, n. 23, Dec. 5, 1949)

This article presents a description of the inspection problems in the manufacturing of ball bearings at the Federal Bearing Co., Inc. at Poughkeep-

sie, N. Y. Considerable detail is given on the manufacturing processes along with the inspection methods employed. Some indications of the use of statistical quality control and chart techniques are given.

THEORY & APPLICATION—GENERAL

THE LAWS OF CHANCE, I, Poisson Series in the Glass Industry & Elsewhere, F. W. Preston, Preston Laboratories, Butler, Pa.
(American Ceramic Society Bulletin, v. 28, n. 6, June 15, 1949)

An excellent technical description of the use of the Binomial Expansion and the Poisson Series in the calculations of probability. Several illustrations are used to show in detail the use of the mathematics involved.

DIVERSIFIED TECHNIQUES INVOLVED IN MULTIPURPOSE QUALITY CONTROL, O. W. Hitchcock, Quality Manager, Scintilla Magneto Div. Bendix Aviation Corp., Sidney, N. Y.
(Steel, v. 124, n. 14, April 4, 1949)

A general non-technical article outlining the relation between quality control and inspection, the statistical methods used for various types of work, and the contacts maintained with both customers and vendors.

Several illustrations show the forms and charts used both for inspection reports and for statistical reports.

STATISTICAL QUALITY CONTROL

What It Really Is—By the Editors of Factory Management & Maintenance.

Why You May Decide to Use It—How to Install It—By C. W. Kennedy, Federal Production Corp.
(Factory Management & Maintenance, v. 108, n. 1, Jan. 1950)

A general description of the use of a standard sampling table. Emphasis is placed on the money saving and quality improving aspects of sampling inspection.

Practical Aids

ELLIS R. OTT, Editor

A Simple Formula for Skewness

RALPH HAERTEL

Stewart-Warner Corporation

Send your "Practical Aid" contribution to:
Dr. Ellis R. Ott
Rutgers University
77 Hamilton Street
New Brunswick, N. J.

ASSUME THAT Table 1 shows a frequency distribution and its associated computation columns for the variable X = time to open (measured in seconds) recorded from tests on 900 thermostats, each designed for use in an airplane subassembly. Suppose further that the average and range charts, based on the 180 samples of 5 each from which these data came, show certain peculiarities that make it a matter of interest to investigate the variation pattern for the variable X.

Examination of Table 1 indicates that we shall be especially interested in the "skewness", or departure from

TABLE 1

Mid-X	f	u	fu	fu^2	fu^3
15	30	0	...	....	.....
30	171	1	171	171	171
45	221	2	442	884	1768
60	162	3	486	1458	4374
75	95	4	380	1520	6080
90	64	5	320	1600	8000
105	42	6	252	1512	9072
120	30	7	210	1470	10290
135	21	8	168	1344	10752
150	19	9	171	1539	13851
165	15	10	150	1500	15000
180	9	11	99	1089	11979
195	8	12	96	1152	13824
210	5	13	65	845	10985
225	4	14	56	784	10976
240	3	15	45	675	10125
255	1	16	16	256	4096
Sums	900		3127	17799	141343

symmetry, exhibited by these data.

We use the variable u for coding these data to cell mid-points; cell width is 15 seconds.

Computations for average, $\overline{X}$, and standard deviation, σ_x, are as follows:

$$\bar{u} = 3127/900 = 3.4744$$
$$\overline{X} = 15 + 15(3.4744)$$
$$\overline{X} = 15 + 52.116 = 67.1;$$
$$(\sigma_u)^2 = 17799/900 - (3.4744)^2$$
$$= 19.776667 - 12.071455;$$
$$= 7.705212$$
$$\sigma_u = \sqrt{7.705212} = 2.776;$$
$$\sigma_x = 15\sigma_u = 41.64 = 41.6.$$

Shewhart *(Economic Control of Quality of Manufactured Product,* p.77) and the *ASTM Manual on Presentation of Data,* p.16, define the skewness statistic k by the formula

$$k = \sum_{i=1}^{n} (X_i - \overline{X})^3 / n(\sigma_x)^3$$

The skewness of a normal distribution is k = 0.

We shall show how to calculate k for the data of Table 1 (or any similar frequency distribution) by a formula that represents considerable simplification over those given by Shewhart and the ASTM Manual, and which is believed to be new. The formula is

$$k = K + 3(C/\sigma_u) + (C/\sigma_u)^3$$

where (in the notation of Table 1) C is a "correction term" defined by $u_o - \bar{u} = C$, with u_o an arbitrary value of the coded variable u, and

$$K = \Sigma f_i (u_i - u_o)^3 / n(\sigma_u)^3$$

The simplest choice for u_o in Table 1 (or any similar table in which data have been coded) is obviously the choice $u_o = 0$. With this choice, we have, for the data of Table 1:

$$K = (141343)/(900)(2.776)^3$$
$$= 141343/19253.11$$
$$= 7.341.$$

Also

$$C = u_o - \bar{u} = 0 - 3.4744$$
$$= -3.4744,$$

whence

$$C/\sigma_u = -3.4744/2.776$$
$$= -1.2516,$$
$$(C/\sigma_u)^3 = (-1.2516)^3$$
$$= -1.961,$$

and therefore

$$k = 7.341 + 3(-1.252) - 1.961$$
$$= 1.624 = 1.6.$$

It is not the object of this paper to discuss the implications of this result, but it may be mentioned that for k as great as 1.6, a mathematical model other than the normal curve would certainly have to be sought to represent the theoretical distribution curve for the variable X in Table 1. Moreover, in seeking an appropriate model for a uni-modal but non-normally distributed variable, an acceptable estimate of the parameter k′ for the universe of the variable would be needed.

For these, and other reasons, the writer feels that the feature of skewness in observed frequency distributions deserves more attention than it has been given in quality control literature. At least *part* of the reason for this apparent neglect must reside in the rather tedious calculations generally required to evaluate k. The simplified formula given in this paper should help to overcome this obstacle.

Even so, k is not as stable a statistic as $\overline{X}$ or σ_x under sampling fluctuations: the ASTM Manual (p.28) recommends a sample of at least 250 before an observed k can be trusted as an estimate of universe skewness, k′. But when one *has* a sample of this size from a controlled process, and organizes these data into a frequency distribution, it would frequently seem both appropriate and desirable to investigate the skewness, and to use the information thus obtained to aid in selecting an appropriate model for the distribution of the variable in question.

An alternative method of working with data whose distribution is skewed is to look for a change of variable that will yield a distribution which is essentially normal. It frequently happens that we can transform our non-normally distributed variable X into a normally distributed variable Y if we choose Y = log X. Other choices are sometimes apparent to those who are familiar with the particular process.

Note: Derivation of the simplified formula for k is not difficult, but will be omitted here.

The method used to obtain the formula for k in this paper can be extended readily to yield a correspondingly simple formula for another statistic defined by $\Sigma(X_i - \overline{X})^4/n(\sigma_x)^4$. This statistic, called "kurtosis," can be compared against the standard 3, which is its value for a normal distribution. A uni-modal (and approximately symmetric) distribution for which this statistic exceed 3 will have a relatively sharper mode and longer tails than a normal distribution; the converse is also true.

Kurtosis is discussed in all standard textbooks on descriptive statistics. Its use in practical quality control is of doubtful value; hence, the simplified formula mentioned above is omitted here.

Report of Second Annual Q.C. Conference

February 10-11—Philadelphia, Pa.

The Second Annual Quality Control Conference, under the joint sponsorship of the Philadelphia and Delaware Sections of the ASQC and Temple University, was held at the University on February 10 and 11.

310 people representing 113 companies, educational institutions, government agencies and ten sections of the ASQC attended the sessions.

A new feature for this year's conference was the inclusion of a panel of five speakers on Business Applications. The discussions of the application of quality control techniques to such fields as clerical work, packaging and consumer research aroused considerable interest among businessmen who are not directly interested in the more usual production and research applications.

Problems Department

G. RUPERT GAUSE, Editor

Submitted by:

MR. W. B. TRAVER
Standard Oil Company of Indiana

For a subgroup size two, the 3-sigma upper control limit for ranges is given in tables as $3.27\bar{R}$, but the upper control limit for standard deviations is given as $3.66\bar{\sigma}$. For a subgroup size two, $R = 2\sigma$ exactly, not approximately, and the two control charts (for ranges and standard deviations) will be identical in their plotted points and averages ($\bar{\sigma}$ and $\bar{R}$) except for the factor of two. However, their upper control limits will be different, and the same sample point could be *in control* on the sigma chart and at the same time *out of control* on the range chart. Why?

Solution by:

HARRY G. ROMIG
Bell Telephone Laboratories, Inc.

The answer to this problem is that exact values of σ_R were used to determine control limits for the range R and only approximate values of σ_σ were used to determine control limits for the standard deviation σ. The committee preparing the ASTM Manual, of which I was a member, made this arbitrary choice when computing the factors in Table I, page 50, Supplement B. The standard deviations for ranges were tabulated (Egon S. Pearson, "The Percentage Limits for the Distribution of Range in Samples from a Normal Population ($n \leq 100$)", Biometrika, Vol. 24, 1932, p. 416, Table A) and the equation for σ_R was given exactly in a complex form with no simple approximation that could be easily remembered. The standard deviation for standard deviations had to be computed and, although the equation for σ_σ in its exact form was not as complex in its exact form as was the equation for σ_R, its approximation $\sigma'/\sqrt{2n}$ was simple and also satisfactory for use with almost all sample sizes, its error being for most practical purposes negligible. It had the added advantage that it was very close to 0.7 of the standard deviation for averages, $\sigma_{\bar{x}} = \sigma'/\sqrt{n}$, for all values of n, thus making it easy to remember and use in the field when no tabulated values of the factors were available.

Problems for solution, and correspondence concerning material published in this department, should be addressed to

MR. G. RUPERT GAUSE
Bell Telephone Laboratories
463 West Street
New York 14, N. Y.

The disagreement in the B_4 and D_4 values for sample size two has been brought to the Manual Committee's attention and it is very likely that the next revision of the Manual will give values of B_4 based on the exact equation, since they are now computed, and since many feel that nothing has been lost by presenting exact factors even though, in the field, many will still make use of the above simple approximation in computing control limits for the standard deviation. This will resolve the entire problem.

The problem as presented concerns itself with the possibility that, due to the discrepancy in these factors for sample size two, a sigma value based on two observations may be within control limits while the corresponding range based on the same two observations will be outside the 3-sigma control limits. For sample sizes other than two, the same situation may also occur because the two statistics σ and R, both measuring variability, have different distributions. However, for sample size two, the nature of the distributions are the same, their difference being only a matter of scale, as indicated in the problem. If both statistics are to be plotted, control limits should be based on the exact limit provided by D_4 for sample size two.

It was not expected that control charts for both standard deviations and ranges would be maintained simultaneously, which would give rise to the dilemma in the problem. The sampling errors for sample size two are so large that the case indicated should happen very infrequently, and if it did occur it is an indication that it may be advisable to make a simple investigation for possible assignable causes in the production process. If the data indicate a trend, it is wise to make a check before trouble really occurs, when such a trend is unfavorable.

The question raised emphasizes the fact that when two or more slightly different tests are made in measuring a property or characteristic of a product, or to check the validity of certain data, lack of control or significant differences may be indicated by one test and not another, depending on the efficiency of the test and the validity of the samples measured or tested. Such different findings indicate that further analysis of the process is required when any one test indicates lack of control.

In summary: (1) theoretically the B_4 and D_4 factors should be identical for sample size two; (2) future tables probably will eliminate the present disagreement; (3) practically, it makes little difference in such marginal cases whether the point is classed in or out. If one or more prior samples of two have been marginal, there is then a more definite indication of lack of control; if they are well within control limits, then one may question whether he should not wait until another sample is available to render a decision.

MATHEMATICAL NOTE

The following relations and values are used in computing the factors in question. For sample size $n = 2$, $D_2 = 1.128$, $1/d_2 = 0.8865$, and $d_3 = 0.853$, where $d_3 = \sigma'_R/\sigma'_x$. Hence,

$$\begin{aligned} D_4 &= 1 + 3d_3/d_2 \\ &= 1 + 3(0.853)\ (0.8865) \\ &= 3.268, \end{aligned}$$

the value listed in Table I, ASTM Manual.

The distribution of standard deviations in samples of n from a normal

universe is known, and is non-normal, particularly when n is small. Considering its exact distribution for samples drawn from a normal universe with unit standard deviation ($\sigma' = 1$), and bringing in a compensating factor for such a distribution, we have

$$B_4 = 1 + 3K/c_2\sqrt{2n}$$

where

$$K = [2(n-1) - 2n(c_2)^2]^{1/2}.$$

Ordinarily the standard deviation of standard deviations is given by

$$\sigma_\sigma = \sigma'/\sqrt{2n} = \bar{\sigma}/c_2\sqrt{2n}$$

where even the c_2 factor may be disregarded when n is greater than, say, 25, because its value is then very nearly one. For small samples (even of size two), disregarding the factor K but keeping the c_2 term, gives, for a normal universe with $\sigma' = 1$, the approximate formula

$$B_4 = 1 + 3/c_2\sqrt{2n}.$$

In particular, for $n = 2$, $c_2 = 0.5642$, $1/c_2 = 1.7725$ and $3/\sqrt{2n} = 1.50$ so that this approximation to B_4 becomes

$$B_4 = 1 + (1.5)(1.7725) = 1 + 2.658 = 3.658,$$

which is the value listed in Table I, ASTM Manual.

For sample size two the factor K becomes

$$K = [2(2-1) - 4(0.5642)^2]^{1/2} = [2 - 4(0.31832164)]^{1/2} = 0.8525.$$

If 2.658 (i.e. approximate $B_4 - 1$) is multiplied by this value of K, we get $(2.658)(0.8525) = 2.266$, which is very near the $(D_4 - 1)$ figure of 2.268 given at the beginning of this note. If more terms in the complex expressions defining σ_R and σ_σ are used in determining both D_4 and B_4, they both become 3.267, as would be expected since for $n = 2$, range and standard deviation are directly proportional, i.e., $R = 2\sigma$.

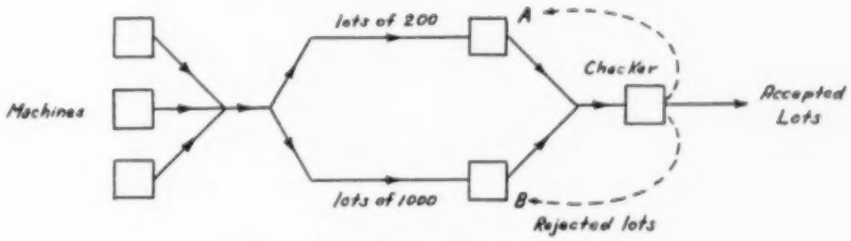
Note on an Inspector Rating Scheme

EDGAR P. KING

Carnegie Institute of Technology

IN RECENT years single sampling plans have been widely used in mass production industries. When handled properly these plans have shown marked success in quality assurance at reduced cost. On occasions, however, serious trouble has resulted from their misuse. The purpose of this note is to call attention to a common industrial problem where mistaken ideas about sampling frequently appear.

Suppose the screw machine department of a particular plant is turning out four percent defective material. After machining, the screws are placed in pans of two different sizes—one having a capacity of 200 screws, the other a capacity of 1000. The lots of 200 are examined by detailer A, the lots of 1000 by detailer B. All lots then pass along a conveyor to a checker who takes a 10% sample from each lot. If he finds one defective screw in the sample, he rejects the entire lot and returns it to the detailer for reinspection. (See the accompanying flow-chart diagram.) The checker keeps a weekly rating sheet on each detailer, based on the number of lots rejected out of a week's work. The question then arises, is such a rating system fair to the detailers?



Flow-Chart for Inspection Routine

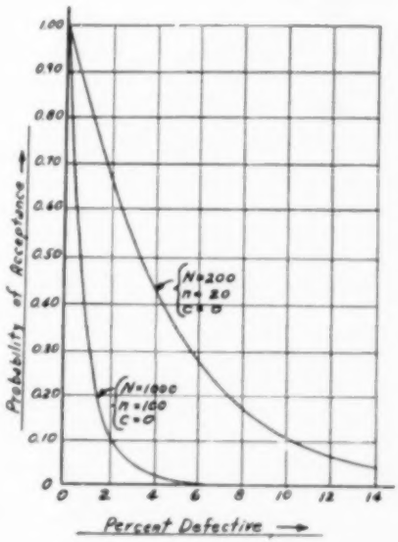


Figure 1—**OC Curves for 10% Sampling**

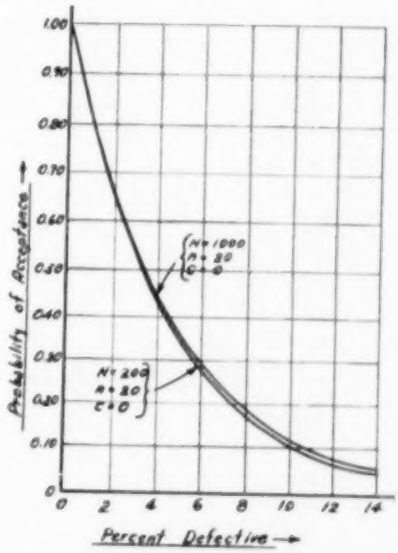


Figure 2—**OC Curves for Fixed Sample Size**

The answer lies in the operating characteristic (OC) curves of the sampling plans. These curves give a picture of the ability of any plan to discriminate between good and bad lots. For any given percent defective in submitted lots, the OC curve shows the probability that such a lot will be accepted by the plan. Figure 1 shows the OC curves by which the checker operates. The curve for small lots is above the curve for large lots, which indicates that lots of 200 nearly always stand a better chance of being accepted than lots of 1000, regardless of the quality of the lots as they reach the checker. For example, 1% defective lots of 1000 will be accepted about 30% of the time, while 4% defective lots of 200 will be accepted about 43% of the time. In plainer language, if detailer B catches 3 out of every 4 bad screws in the large lots and detailer A lets the small lots pass straight from the machine to the checker, A still gets a much higher rating.

The use of such a scheme arises from the mistaken idea that all 10% sampling plans give the same protection. Actually, from the standpoint of protection, the absolute size of the sample is much more important than the ratio of sample size to lot size. For example (Figure 2) by using a sample of size 20 in both cases the checker would be operating on almost identical curves for both detailers—B's lots would have approximately the same chance of acceptance as A's lots. Control charts could then be plotted from the checker's results to compare the performance of the two inspectors.

The general nature of the results obtained does not depend on the particular choice of process average or the ratio of sample size to lot size, i.e., the particular percentage sampling plan being used. The 4% process average and 10% sample were chosen only to simplify the calculations.

In actual practice, of course, the problem is complicated by the fact that there are many inspectors, each inspecting many different lot sizes. Even so, the same general principle applies: Keep the sample size constant!

AMERICAN SOCIETY NEWS

Printing of Industrial Quality Control

With this issue of INDUSTRIAL QUALITY CONTROL, printing of the magazine has been shifted from Buffalo, N. Y. to the Wisconsin Cuneo Press, Inc. in Milwaukee, Wisconsin.

This change is the first of a number of steps being taken by the Editorial Board and the Executive Committee to improve Society organization for publications and to assist in prompt and efficient handling of these publications.

Other steps taken in these planned changes will be announced in subsequent issues of the magazine.

Executive Committee Meets at Princeton

The Executive Committee of the Society held a successful two-day meeting on Saturday and Sunday, December 2 and 3, at Princeton, New Jersey, following the Middle Atlantic Regional Conference. All but three of the members of the Executive Committee were present and one of those absent was represented by the Alternate Regional Director.

The Executive Secretary presented a report on Society membership as of November 28, 1949, showing a total membership of 2037 of whom 66 were Fellows, 814 were Senior Members, and 1145 Members. (Of the total 2037 membership, 532 were new members of the Society.) It was agreed that each Regional Director will work with the Directors in his Region so that each Section will secure the highest possible renewals and new memberships during the current Society year.

The Treasurer presented a report showing Society funds on hand in the current account amounting to $7,697.12 as of November 30, 1949. Income received during the first five months of the current year totalled $7,511.15 and disbursements during the same period amounted to $5,-639.29. The budget adopted at the October meeting of the Executive Committee was reviewed in the light of these operating figures.

Each Regional Director reported on Society activities and program in his Region and presented the recommendations of the Sections on Society operating procedures, membership renewal procedures, and dues schedules. Based on these reports, plans were made for strengthening Society organization through the work of Directors and Regional Directors. Vice President Weaver presented a proposed "Manual of Procedure for Directors and Regional Directors" as requested by the Executive Committee in October. This document was carefully reviewed and approved for submission to the Directors for study and comments.

The Special National Offices Committee reported on its review of Society operations in national offices. Based on this review, recommendations were made to modify and simplify Society procedures so as to lighten the load of work of national officers. These recommendations were accepted by the Executive Committee with thanks to the Special Committee.

In order to assist the Editorial Board in adopting new procedures regarding Society publications, a Special Publications Committee was established consisting of W. R. Weaver (Chairman), A. L. Davis, F. J. Halton, M. E. Wescott, and R. E. Wareham. This committee was directed to work closely with the Editorial Board and Advertising Committee in establishing new procedures for handling publications.

The Executive Committee received reports from Society committees as to activities and programs of the respective committees. A proposed "Standard Definitions and Symbols for Control Charts" was received from the Standards Committee and approved for publication in Industrial Quality Control.

After considerable discussion, the Executive Committee approved the request of the Denver Section that it be represented in Society affairs as part of the Midwest Region rather than the Western Region, so as to continue the close contact of Denver people with the Midwest Sections.

The Executive Committee voted to establish a General Convention Committee to serve the Society in matters of policy relating to conventions and conferences. The President appointed the following as members of the General Committee: W. R. Weaver (Chairman), J. M. Ballowe, A. L. Davis, W. R. Purcell, R. S. Saddoris, and W. E. Jones.

Numerous other matters were given detailed consideration at the meeting, and action taken in connection with a number of them is recorded elsewhere in this issue of the magazine.

Chemical Technical Committee Established

The Executive Committee has established a new Technical Committee to serve the Society in matters relating to chemical quality control matters. The new committee has been designated the Chemical Technical Committee and is composed as follows:

Chairman: Roland H. Noel
Syracuse, N. Y.

Vice Chairman: George N. Cornell
Decatur, Ill.

Secretary: Charles A. Bicking
Wilmington, Del.

The new Chemical Technical Committee is expected to be of important value to Society members by serving as a common ground for those working in the chemical field. While specific questions will be referred to the Committee from time to time, there are four principal projects which the Committee now plans to undertake.

1. Preparation of a Bibliography of articles involving quality control articles in the chemical field.
2. Service to the Editorial Board in advising on quality control papers dealing with chemical problems.
3. Assistance to Convention committees in planning of convention programs for chemical applications.
4. Acting as a clearing-house for matters of quality control of interest to members working in the chemical industry.

Members of the Society who are interested in the work of the new committee are urged to write to the Chairman of the Committee, Mr. Roland H. Noel at Bristol Laboratories in Syracuse, N. Y.

1950 Annual Convention

Plans are well advanced for the Society's Fourth Annual Convention to be held at the Milwaukee Auditorium in Milwaukee on June 1 and 2. Under the leadership of General Chairman R. S. Saddoris and Program Chairman L. A. Knowler, an excellent program is being arranged which should prove of interest and value to all members of the Society.

The Annual Dinner Meeting of the Society will be held on Thursday evening, June 1, at the Hotel Pfister in Milwaukee. At this meeting, the Shewhart Medal and the Brumbaugh Award will be presented to those selected for this year.

Following the Convention, on Saturday, June 3, the annual corporate meeting of the Society will be held in Milwaukee for election of 1950-51 officers and for transaction of other Society business. All members are urged to plan to attend both the Convention and the annual meeting.

MICHIGAN QUALITY CONTROL COURSE

The University of Michigan will offer a ten-day course in Statistical Quality Control August 21-31 inclusive on the campus in Ann Arbor. This will be a repetition of the successful introductory course given in August in 1948 and 1949. It will be intensive, mathematically non-technical, and practical.

Professor C. C. Craig will be in charge, and the staff will include Professors I. W. Burr of Purdue University and E. G. Olds of Carnegie Institute of Technology and Mr. E. C. Yehle of the University of Michigan. The registration fee of $100 per person includes a textbook and a syllabus of the course.

For further information write to Professor C. C. Craig, 106 Rackham Building, University of Michigan, Ann Arbor, Michigan.

SQC COURSE
Washington University
St. Louis, Mo. April 17-29
For details write to
J. H. Batchelor, Director
University College
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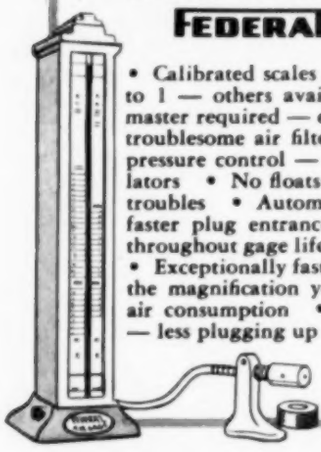

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